APPLIED FUNDAMENTALS of MACHINES

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— Related Shop Science Series —

McKNIGHT & McKNIGHT

BLOOMINGTON, ILLINOIS

LITHOGRAPHED IN U. S. A.

FOREWORD

For the past several years, it has been my privilege to associate with the authors of this book and watch the development of the Vocational Science Series of books at the Huntington East High Trades School. The authors are eminently fitted to prepare a practical treatise on *"Applied Fundamentals of Machines"* because of their training and experience, scholastically and as craftsmen, and through their wide contacts with present day Trades and Industries.

"Applied Fundamentals of Machines" is another in a series of books prepared to provide war-enriched courses in practical science and mathematics. The books *"Methods of Measurement"* and *"Principles of Electricity"* have already taken their place in this field, with others still to follow. They are designed for day school or evening classes, giving the necessary preliminaries or background for the specialized occupations required by modern armed forces as well as in present day industrial plants.

Each publication treats the learning units in an interesting, yet practical manner. In addition to instruction concerning procedure, each assignment is supplemented with well illustrated information units and ample numbers of reports or tests. The presentation provides for a maximum of individual progress by the trainee and individual instruction by the teacher.

It is my belief that the use of the materials found in this series of books should make a definite contribution in supplying the flow of trained man-power needed in this Nation.

P. T. McHenry
State Teacher Trainer
Trade and Industrial Education

Charleston, W. Va.
April, 1944.

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of the following firms and corporations in supplying information, electrotypes and photographs for use in compiling and illustrating this book. In all cases their splendid cooperation has been a source of much encouragement and satisfaction.

South Bend Lathe Works, South Bend, Indiana
Brown and Sharpe Mfg. Co., Providence, R. I.
Tinius Olsen Testing Machine Co., Philadelphia, Pa.
Wilson Mechanical Instrument Co., New York City
New Departure, Div. of General Motors Corp., Bristol, Conn.
W. A. Jones Foundry and Machine Co., Chicago, Illinois
Chrysler Corporation, Detroit, Michigan
American Car and Foundry Co., Huntington, West Virginia
Timken Roller Bearing Co., Canton, Ohio
Hyatt Bearings Division, General Motors Corp., Harrison, N. J.
SKF Industries, Inc., Philadelphia, Pa.
Central Scientific Company, Chicago, Illinois
Pure Oil Company, Chicago, Illinois
Sun Oil Company, Philadelphia, Pa.
A. Schrader's Son, Brooklyn, N. Y.
A. C. Spark Plug Division, General Motors Corp., Flint, Mich.
DeVilbiss Co., Toledo, Ohio
Blaw-Knox Company, Pittsburgh, Pa.
Chevrolet Division of General Motors Corp., Detroit, Michigan
The Carborundum Company, Niagara Falls, N. Y.
The Frederick Iron and Steel Co., Frederick, Md.
Johns-Manville, New York
Eclipse Aviation, Bendix, N. J.
General Motors Corp., Research Laboratories Division, Detroit, Mich.
Servel, Inc., Evansville, Indiana
International Harvester Company, Chicago, Illinois
W. M. Welch Scientific Co., Chicago, Illinois
Link-Belt Co., Chicago, Illinois
Gear Grinding Machine Co., Detroit, Michigan

We wish to acknowledge the cooperation of Mr. H. A. Lightner, Coordinator of the Huntington East High Trades School and Mr. P. T. McHenry, State Teacher Trainer in the accomplishment of this undertaking. We are also indebted to Miss Helen Diddle for her work in typing the manuscript and to the various shop instructors for the suggestions and cooperation they have given us. The excellent line drawings were made by students of the Mechanical Drawing department, Mr. W. A. Childs, instructor.

W. H. CORNETET
D. W. FOX

INTRODUCTION

The purpose of this course is to teach the basic principles of machines as applied to modern life. We realize more and more that this is a mechanized world, machines being used to accomplish tasks heretofore considered as impossible. Modern warfare requires an army of specialists, men who are trained in applied mechanics. Without such men we will be entirely incapable of attaining the goals we have set for winning the struggle to free the world of oppression and dictatorship.

Much of our present day knowledge, applying machine principles, is the result of research and experimentation by men who counted on and received little personal or financial reward. Many seemingly foolish experiments and discoveries are today the basis of machine operations, indispensable to our way of life. In this book a definite attempt has been made to show important industrial applications of essential theory, in order to produce an intelligent mechanic.

To carry out this study of machines, most jobs are set up in the following manner:

Information Series

Wherever it is found necessary, an information unit is included containing an explanation of the theory needed. This is intended to supplement information which is to be secured from various textbooks, many of which are cited in special references. Vocabulary lists are placed at the end of many of these information units to aid the student in mastering the meaning of new words and terms. Since the student may find other words which he does not understand during his reference reading, space is provided in which he may record these terms and their meaning. These information units are also valuable for review purposes.

Operative Series

These are assignment units written for each job involved. They contain instructions explaining the method of procedure and questions, intended to focus the student's attention on the more important facts.

Objective and Mastery Tests

In order to check on the learning accomplishments of the student, objective tests on various phases of the course and a comprehensive test covering the entire unit are included as a supplement to the book.

Study Procedure

A workman is known by the type of shop he keeps. It is just as true that a student is judged by his study habits. To improve your study habits the following suggestions are made.

1. Study as many up-to-date reference materials as are available for a complete understanding of the new job to be attempted. You can profit much by the experience of others.

2. When an experiment is to be performed in the laboratory, have your work planned so as to make efficient use of your time. Know what is to be

done and what materials you will need. Take good care of your equipment and be accurate in your observations. Inaccurate results are useless. When an experiment is completed, be sure to return all your materials to the stock room and clean up your worktable.

3. Keep a neat record of your work. Write your answers plainly. When in doubt, write your answer on a piece of scrap paper, then when you find your answer is correct, place it neatly in your book. When solving problems, arrange your work in a systematic order, indicating the units with which you are working. Multiplications and divisions should be carried out on scrap paper, the results only being recorded in your book.

4. Have your work checked and approved at the end of each assignment, then proceed to the next lesson.

CONTENTS

Foreword 4
Acknowledgments 3
Introduction 5–6
Properties of Materials 9–18
Measurement 18–26
Precision Instruments 26–34
Theory of Machines 34–42
Power 42–60
Machines 60–62
Friction 62–75
Simple Machines 75–84
Center of gravity 84–94
Pulley systems 94–99
Axle 99–116
Gears and gearing 116–127
Gear trains 127–141
Hydraulics 141–151
Machines utilize properties of molecules 152–158
Elasticity — Hooke's Law 158–173
Viscosity 173–176
Surface tension 176–177
Capillarity 177–178
Lubrication 178–186
Solutions and emulsions 186–191
Measuring Specific Gravity of Liquids 191–192
Oil Mixtures and Sludge 193–196
The Gas Laws 196–200
Internal Combustion Engines 200–214
Bernoulli's principle 214–218
Forces 218–226
The Simple Derrick 226–236
Types of Motion 236–240
Laws of Motion 240–256
Heat 256–276
Refrigeration 276–282
Heat transfer Essential in Heat Engines 283–294
Chemistry of combustion 294–304
Petroleum 304–310

APPLIED FUNDAMENTALS OF MACHINES

PROPERTIES OF MATERIALS

THE MECHANIC WORKS WITH MATTER

"Mechanics" may be defined as that part of physical science which deals with the action of forces on bodies. It is necessary to have in mind the fundamental laws of matter, such as the laws of force and motion, in order that we may make practical application of the principles of physics in the operation of machines.

There are certain self evident facts concerning matter with which we may begin. Matter is said to be any substance that occupies space and has weight. The fundamental law of matter is that it can neither be created nor destroyed. This is known as the law of the Conservation of Matter. In the past it was thought that matter could neither be increased nor decreased in amount, but recent facts indicate that some kinds of matter can be decreased. This is accompanied by a liberation of a considerable amount of energy. Likewise, energy has been transformed into matter. Therefore energy must be included in the definition of matter and its conservation.

Matter may exist in three physical states: namely, solid, liquid, or gas. A *solid* is matter having definite form and volume, not easily changed by mechanical force. A *liquid* is matter having a definite volume, but being a fluid, it assumes the shape of its container. A *gas* possesses mass only, having neither volume nor shape. Gases are very different from liquids and solids in that gases, having no definite volume, are compressible; solids and liquids are highly incompressible.

Centuries ago, the ancient Greeks reasoned that matter was made up of infinitely small particles, much as sandstone is made up of grains of sand. These small particles are now called molecules. The molecule is the smallest particle of a substance that can exist alone and retain the characteristic properties of the whole mass.

A mixture of hydrogen and oxygen gases may be burned (combined chemically) and water is the product. A current of electricity passed through the water thus formed, again separates the hydrogen from the oxygen. This shows that the smallest particle of water is the *molecule*, although it is made up of *atoms* of hydrogen and oxygen.

Molecules are constantly in rapid motion, the motion becoming more rapid with an increase in temperature This motion is greatest in gases, less in liquids and least in solids. Molecules move in straight lines until they strike another molecule or the sides of their container, bouncing off with perfect elasticity.

The molecule is a very small particle of matter, but the distance between molecules of a gas is great compared to their diameters. At standard temperature (0° centigrade) and standard pressure (760 mm. of mercury), the average distance between the molecules of a gas is about 1000 times

their diameter. In liquids and solids, the molecules are close enough to each other that they exhibit a tendency to stick together. This tendency, called cohesion, is greatest in solids. Molecules escape from the surface of a body into surrounding space, a process called evaporation. This tendency is greatest in liquids but does occur in solids. For example, a cake of napthalene (moth balls) will evaporate and completely disappear. Heat increases the tendency to evaporate by increasing the speed of molecular motion. Boiling is a rapid escape of molecules from the surface of a liquid into the space above.

The molecular theory makes it possible to explain many physical phenomena. It is generally accepted as a fact and aids in understanding the many changes which matter undergoes.

GENERAL PROPERTIES OF MATTER

Properties are those characteristics by which matter may be described and identified. There are certain properties common to all matter, yet many substances have special properties, peculiar to them. Some of these general and specific properties will now be considered.

MASS

All bodies possess *mass*. Matter has been defined as any thing having weight and occupying space. Mass is *quantity* of matter. It must not be confused with volume or weight. Some matter, such as a sponge, may be very porous; its matter is spread out and loosely joined. Steel is very compact and dense. Mass is an inherent property of all matter and is characterized by possessing inertia.

WEIGHT

All substances on the earth attract each other with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers.

$$F = \frac{M_1 \, M_2}{d^2}$$

The earth, therefore, attracts all substances to it. This attraction, following the law just given, is called gravity and is expressed as weight. The weight of a body is the measurement of the attraction of the earth upon its mass. The weight of a substance changes with change of quantity of mass, or with a change of distance between the centers of the masses. For example, a given mass will not weigh as much on top of a high mountain as at sea level. The difference is very small but can be measured. Since the earth is flattened slightly at the poles, the earth's surface here is approximately 100 miles nearer the center than at the equator. The same object weighed at the equator and at the poles will weigh differently but have the same mass. It is common and practical however, to express mass as weight since it is always proportional to it.

VOLUME

The volume of a mass may vary with its compactness. Volume is expressed as the product of length, breadth and thickness. The volume of a

given mass of gas may be changed quite easily. The volume of a liquid or solid may be changed with difficulty. The expansion and contraction of substances demonstrates the porosity of matter, also that the volume may change without any variation in the actual mass.

INERTIA

Inertia is a property of all matter. It is that property of matter which causes a body to remain at rest or in motion and to resist any attempt to change these conditions. For example, a large amount of force is neces-

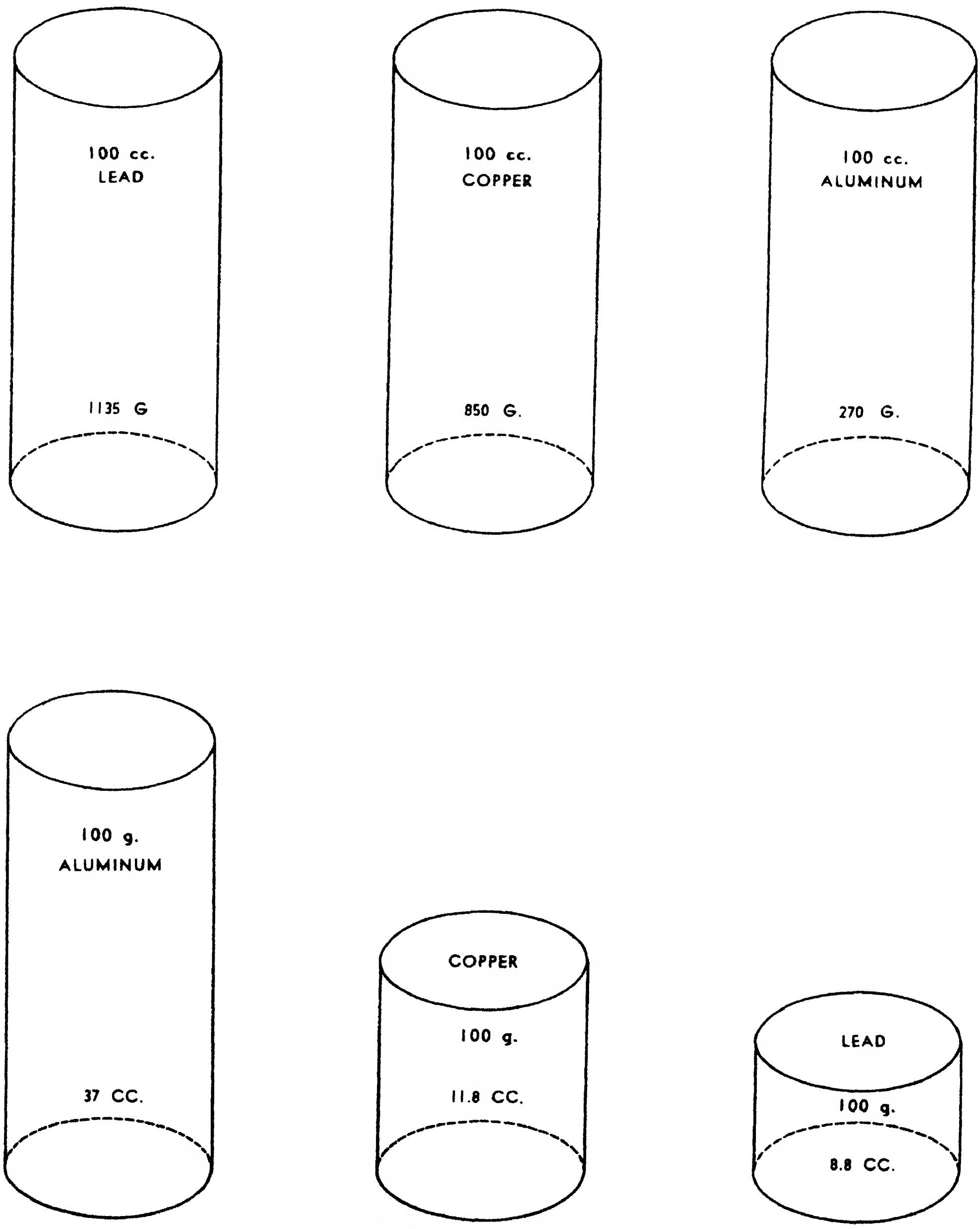

FIG. 1. DIFFERENCE IN WEIGHT AND VOLUME.

sary to set an automobile in motion. After the car is in motion, a large amount of force on the brakes is required to stop it, for it resists any attempt to change its condition of rest or motion. An automobile has a powerful motor and system of gears which are used primarily to overcome inertia at the start and to increase the speed of the car.

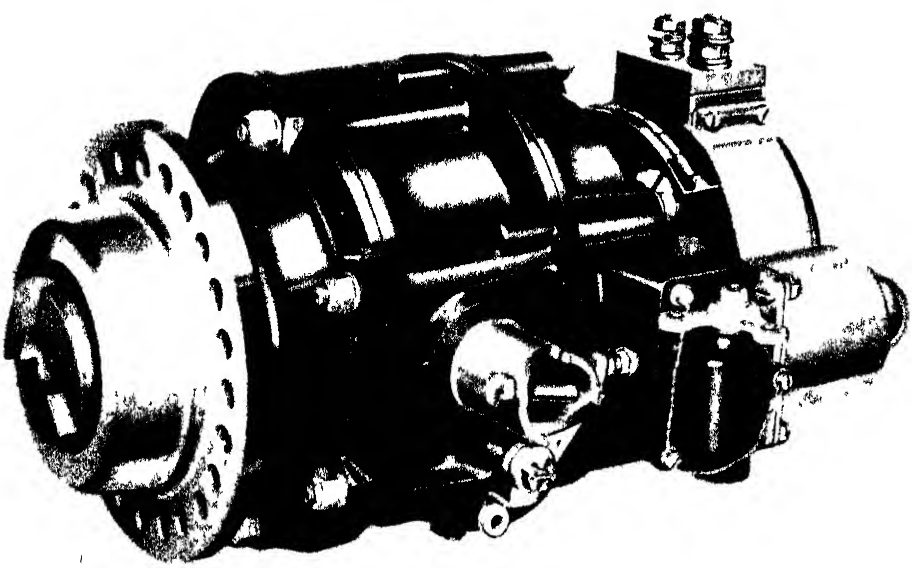

FIG 2. TYPICAL ECLIPSE DIRECT CRANKING AND INERTIA ELECTRIC AVIATION ENGINE STARTER. (Courtesy, Eclipse Aviation Division, Bendix Aviation Corporation.)

Illustrated in Fig. 2 is an electric motor which is used to start an airplane engine. This starter combines the features of inertia and direct cranking electric starters. An electric motor accelerates a flywheel to 16,000 r.p.m. Through reduction gearing, this stored-up energy spins the crankshaft to overcome the original starting load. The electric motor continues cranking until the engine fires.

IMPENETRABILITY

It is self evident that two bricks cannot occupy the same space at the same time. This is also true of molecules. Sugar dissolved in water may seem tc be an example of two bodies occupying the same space at the same time, but since substances are porous, the sugar molecules fit in between water molecules. This inability of two substances to occupy exactly the same space at the same time is known as "impenetrability."

Other special properties of matter which have importance are tenacity, ductility, malleability and hardness. These properties must be considered in selecting materials to be used in the construction of various machine parts, or in the handling of these parts by the mechanic. These properties will be studied in greater detail later, but are briefly described here.

TENACITY

Molecules have an attraction for each other. Molecules of the same kind attract each other with a cohesive force while molecules of different

kinds attract each other with an adhesive force. These properties of molecules account for the fact that substances hold together.

The use of ropes, cables, chains, tie rods, etc. depends on the tenacity of matter. The property of materials by which they resist being pulled apart is known as tensile strength. A large testing machine used for making tensile tests is shown in Fig. 3A. This machine is designed to make tests on pieces of large dimensions. The usual size test piece is shown in Fig. 3B. It has a diameter of .505″ (before pulling) and is threaded on

FIG. 3A. MAKING A TENSILE TEST. (Courtesy, Tinius Olsen Machine Co.)

FIG. 3B. STANDARD .505″ TENSILE TEST SPECIMEN. (After breaking.)

both ends for fastening in the testing machine. Since a circle having a diameter of .505" has a cross sectional area of .2 square inches, the tensile strength in pounds per square inch (PSI) can be determined by multiplying the breaking force by 5.

DUCTILITY

In forming wire, slender rods and tubes, it is necessary to draw material through openings in dies. Since molecules cling together by cohesive force, a substance is said to be ductile if it holds together when drawn through a die. A wire drawing die, Fig. 4B, is a small plate containing one or more tapered holes called "die holes." The material surrounding the die hole must be extremely hard to withstand the frictional wear of drawing the wire. Four hard materials are now used for wire die holes, namely, chilled cast iron, alloy steel, tungsten carbide and the diamond.

FIG. 4A. DRAW BENCH, COLD DRAWN ROD.

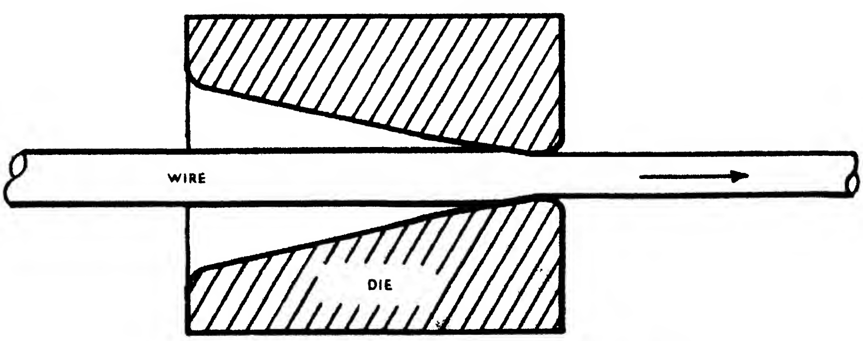

FIG. 4B. DRAWING A WIRE THROUGH A DIE.

Tungsten carbide is rapidly becoming the most used material for this purpose. Metals are very ductile substances, varying in ductility. Gold is the most ductile of all metals.

The following list shows the order of ductility of a few of the more common metals:

1. Gold	4. Iron	7. Zinc
2. Silver	5. Nickel	8. Tin
3. Platinum	6. Copper	9. Lead

Wires finer than a hair have been drawn for use in sensitive instruments. Ductility is measured by the amount of distortion or strain a body undergoes in being ruptured by a tensile test. It is measured by the percentage of elongation or reduction in cross-sectional area of the ruptured sample or test piece.

MALLEABILITY

Cohesion holds molecules together when force is used to roll metal out in the form of a sheet. Hammering or rolling a substance causes the molecules to slip and slide over one another.

The ability of a substance to hold together under such a stress is called malleability. Most metals are rolled into sheets or plates while the metal is hot because the molecules cohere better at a high temperature, without rupturing. A few metals are very malleable at ordinary temperatures, gold being the most malleable of all metals.

The following list shows the order of malleability of a few of the more common metals:

1. Gold	4. Tin	7. Zinc
2. Silver	5. Platinum	8. Iron
3. Copper	6. Lead	9. Nickel

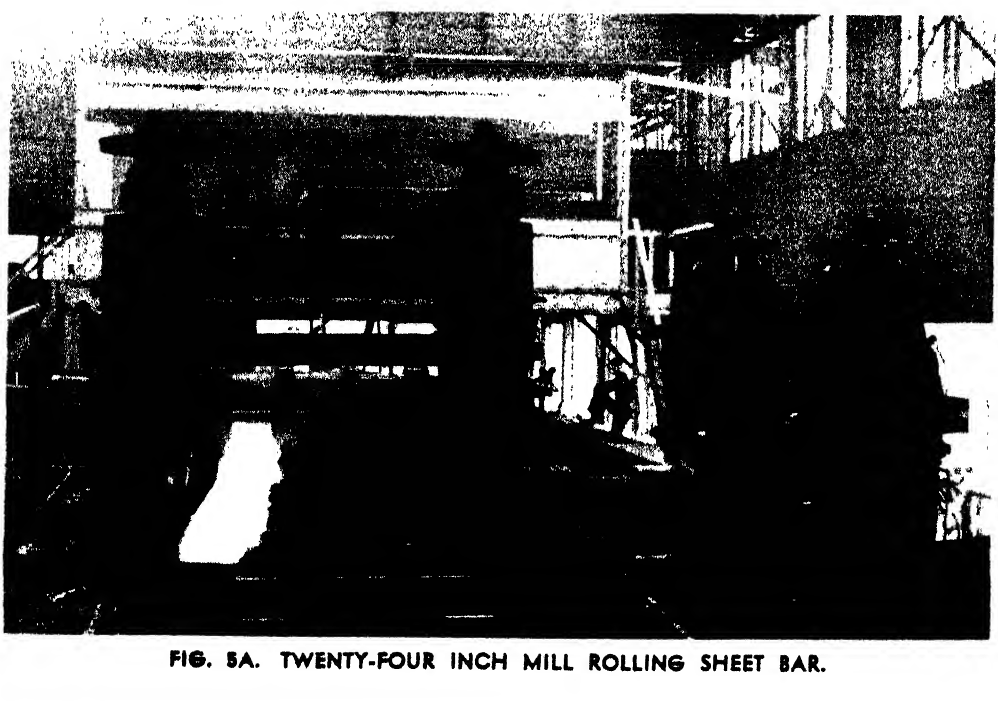

FIG. 5A. TWENTY-FOUR INCH MILL ROLLING SHEET BAR.

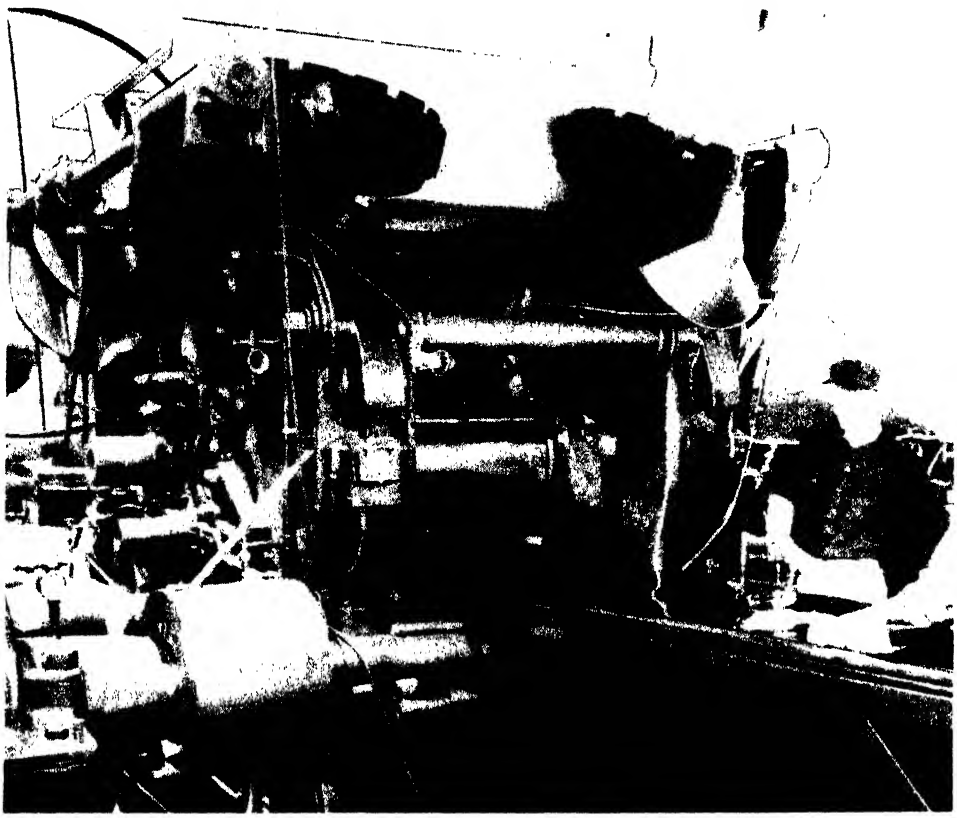

FIG. 5B. HIGH PRESSURE MILL COLD ROLLING SHEETS.

HARDNESS

Hardness is the ability of a substance to resist penetration or abrasion. There are several methods for determining the hardness of a material depending upon conditions under which it is to be used. Two of the older methods of testing hardness are the scratch test, devised by Moh, and the file test. A scale similar to the one devised by Moh is shown here.

Hard	10. Diamond
	9. Emery
	8. Topaz
	7. Quartz
	6. Iridium
	5. Iron
	4. Platinum
	3. Copper
	2. Aluminum
Soft	1. Talc (soapstone)

In using this test, the relative hardness of a substance is determined by finding which of the materials in the list will scratch it. Brass has a hardness of 3.5. This means that it can be scratched by platinum but not by copper.

The file test is made by running the edge of a file across a substance

slowly while firmly pressing it against the material. If the file does not "bite," the material is said to be file hard. Since neither of these methods can be standardized, other more exact methods have been developed. The more common of these are the "Brinell," "Rockwell" and "Scleroscope" methods. A standard Rockwell testing machine is shown in Fig. 6. This machine, using either a diamond or $\frac{1}{16}$ inch steel ball bearing penetrator, measures the resistance to indentation (hardness) automatically.

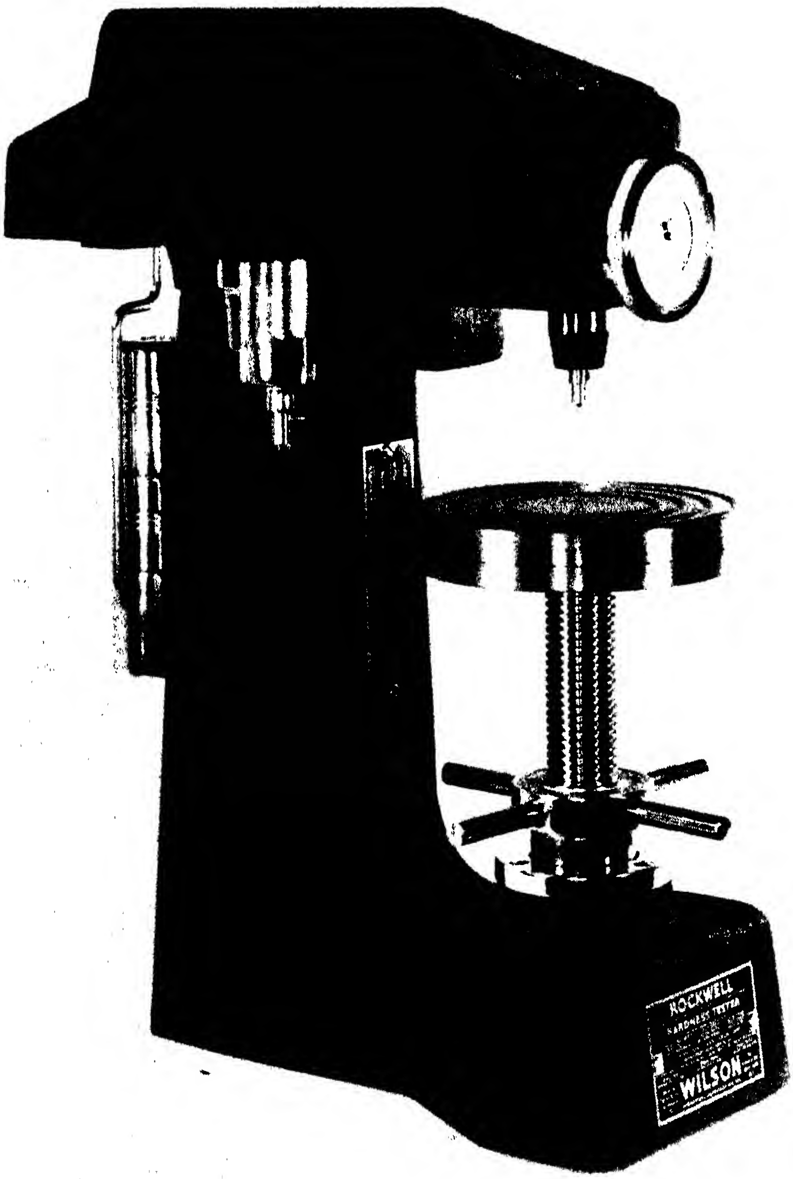

FIG. 6. ROCKWELL HARDNESS TESTER. (Courtesy, Wilson Mechanical Instrument Co.)

New Words:

ADHESIVE.—Tending to stick together. The molecular attraction exerted between the surfaces of dissimilar bodies in contact.

ABRASION.—The wearing away of a substance by rubbing with a harder material.

ATOM.—The smallest particle of an element. Molecules of compounds are made up of atoms of elements.

CENTIGRADE.—The metric system of measuring temperature. Water freezes at 0° and boils at 100° on the centigrade scale.

COHESIVE.—Similar surfaces sticking together. The ability of a substance to hold together.

COMPRESSIBLE.—Capable of being compressed or pushed into a smaller volume.

DIE.—A tool used to impart a desired shape to a piece of material which is being drawn through it or pressed against it.

ELASTICITY.—Quality or state of being elastic; springiness. The property a body possesses by which it recovers its former shape and size after the removal of an external pressure or altering force.

FLUID.—Having particles which easily move and change their relative position without separation of the mass; capable of flowing.

INHERENT.—Permanently existing in something; an essential part of anything by nature.

INERTIA.—The property of matter by which it remains at rest, or in uniform motion, unless acted upon by some external force.

MASS.—Quantity of matter.

MOLECULE.—Smallest particle of a substance having the same properties as the whole mass.

POROSITY.—Quality of being porous; having spaces in the substance of the body.

STANDARD PRESSURE.—Pressure exerted by the atmosphere at sea level. It is equal to 14.7 lbs. per sq. inch and is capable of supporting a column of mercury 760 mm. high.

Additional New Words:

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MEASUREMENT

MEASUREMENT

The units most commonly used in measuring matter are those of length, volume and weight. Two systems are in use, the metric and English.

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LENGTH

The Standard yard, legalized in England in 1824, is the standard for measuring length in the United States. It is commonly subdivided into feet and inches, thus —

1 yard (yd.) = 3 feet (ft.) = 36 inches (in.)

There are two systems for subdividing the inch, namely the "binary" and the "decimal." In the binary, the inch is divided by two, this in turn, by two; and so on, thus — 1 inch; $\frac{1}{2}$ inch; $\frac{1}{4}$ inch; $\frac{1}{8}$ inch; $\frac{1}{16}$ inch; $\frac{1}{32}$ inch; $\frac{1}{64}$ inch. In the decimal system, the inch is divided by ten, this in turn by ten, and so on, thus — 1 inch; .1 inch; .01 inch; .001 inch.

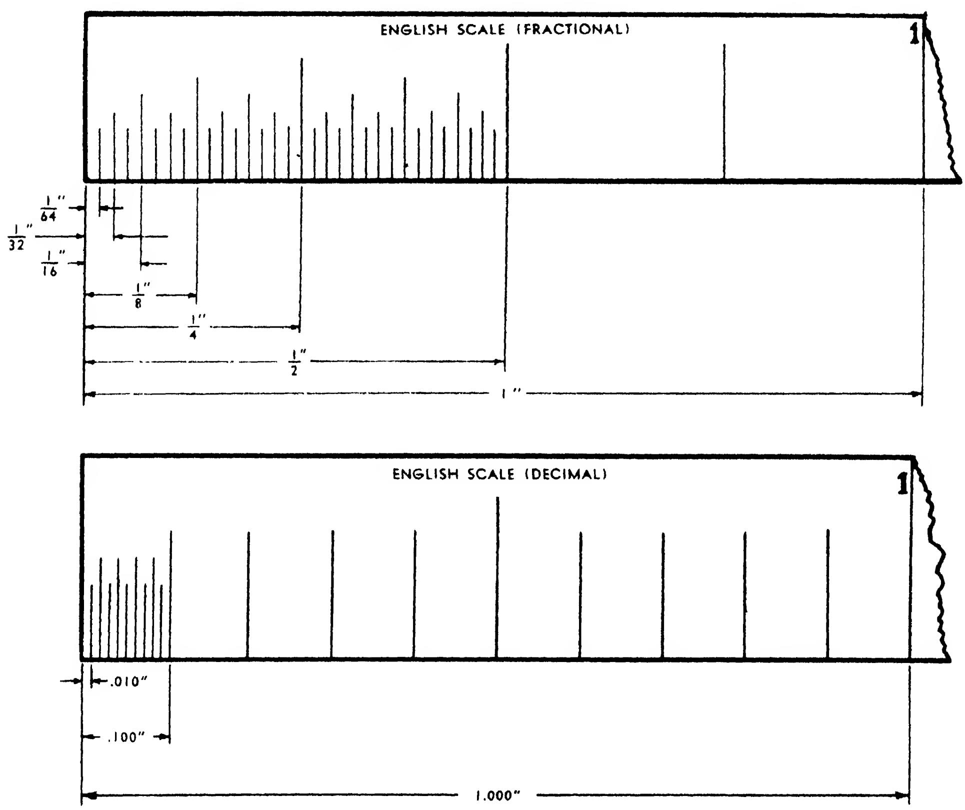


FIG. 7.

The metric system of measurement was legalized as a standard in the United States in 1866, but its use was made optional.

The decimal system is much simpler to use than the English system because each larger unit is ten times the previous smaller unit. Contrast this with the subdivisions of the English units, for simplicity.

The standard of length in the metric system is the meter (m). It was originally intended to be 1/10,000,000th of the meridian between either of the earth's poles and the equator. Since this is now known to be slightly in error, the meter is best defined by saying that it is the distance between two fine scratches on a bar made of an alloy of platinum (Pt) and iridium (Ir) metals, at 0° centigrade, which is kept in the International Bureau

of Weights and Measures at Sevres, near Paris, France. An exact duplicate of this bar is also to be found at the Bureau of Standards in Washington, D. C.

The meter is subdivided as follows — tenths, or decimeters; hundredths or centimeters and thousandths or millimeters. Multiples of the meter are the dekameter, or ten meters; hectometer or one hundred meters and the kilometer or one thousand meters. These units with their abbreviations are summed up in Table I.

METRIC UNITS OF LENGTH

10 millimeters (mm)	=	1 centimeter (cm)
10 centimeters	=	1 decimeter (dm)
10 decimeters	=	1 meter (m)
10 meters	=	1 dekameter (dkm)
10 dekameters	=	1 hectometer (hm)
10 hectometers	=	1 kilometer (km)

TABLE I

A rule divided in the metric system, is shown in Fig. 8.

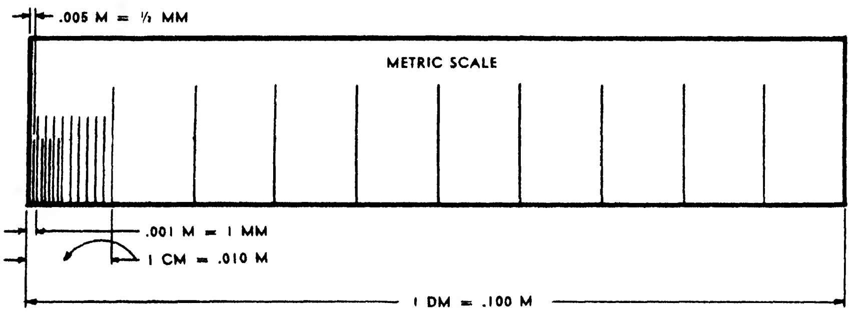


FIG. 8.

METRIC PREFIXES

One of the simplicities of the metric system is the use of the same prefixes when measuring length, volume and weight. These prefixes are listed in Table II and should be memorized.

METRIC PREFIXES

Fractional (from Latin)		*Multiple (from Greek)*
milli = 1/1000 or .001		deka = 10
centi = 1/100 or .01		hecto = 100
deci = 1/10 or .1		kilo = 1000

TABLE II

In measuring length with a rule, care should be taken to turn the instrument so that the graduations align themselves with the edge of the object being measured. This is shown in Fig. 9. This diagram also shows that it is best to begin measuring from some point within the rule since the end of the rule often is inaccurate, due to wear.

VOLUME

Since volume is three-dimensional, different units are required for its measurement. In the metric system there is a direct relationship between the units for length and volume; this is not true in the English system.

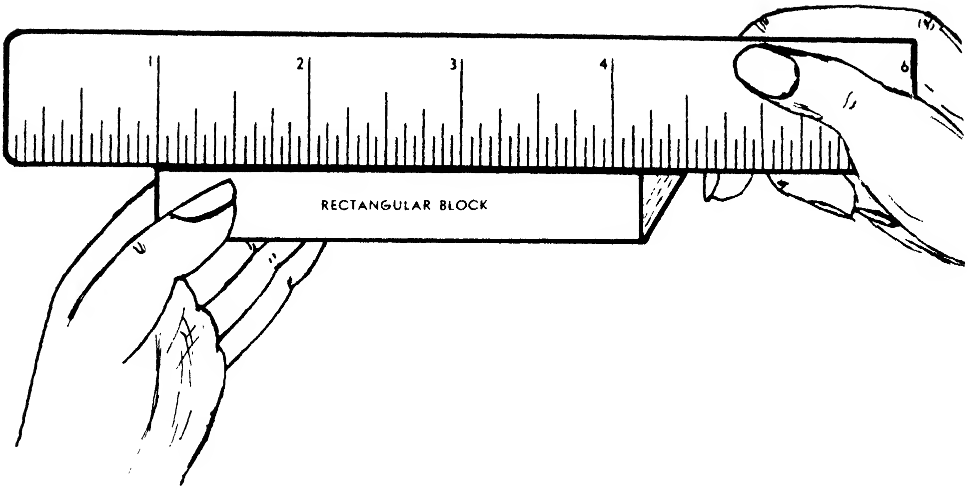


FIG. 9.

The more common English units of volume are shown in Table III.

LIQUID MEASURE			
4 gills	=	1	pint
2 pints	=	1	quart
4 quarts	=	1	gallon
31.5 gallons	=	1	barrel

TABLE III

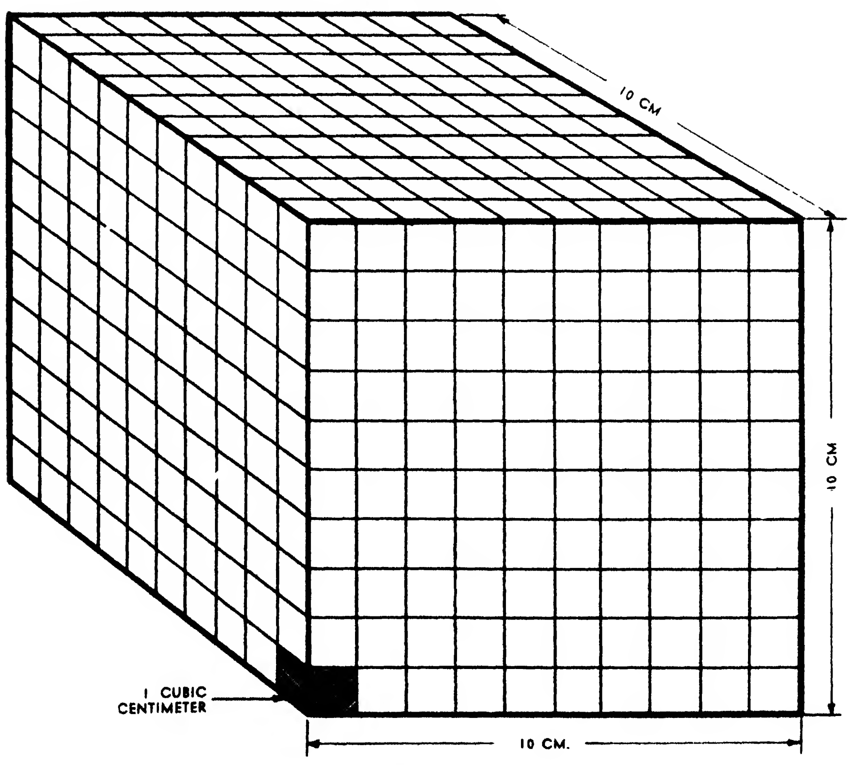


FIG. 10.

The metric unit of volume is the liter (l) Fig. 10. It is the space occupied by a cube 10 cm. on each side. Since volume is calculated by multiplying the three dimensions, width, length and thickness, i. e.

$$V = LWT$$

this cube contains 10 x 10 x 10 or 1000 cubic centimeters. The metric units of volume are shown in Table IV.

METRIC UNITS OF VOLUME

1 milliliter (ml)	=	.001	liter
1 centiliter (cl)	=	.01	liter
1 deciliter (dl)	=	.1	liter
1 dekaliter (dkl)	=	10	liters
1 hectoliter (hl)	=	100	liters
1 kiloliter (kl)	=	1000	liters

TABLE IV

It will be noticed that a milliliter and a cubic centimeter are the same. When measuring small volumes of liquids, an instrument known as a graduated cylinder, Fig. 11, is used. Since water and similar liquids have great

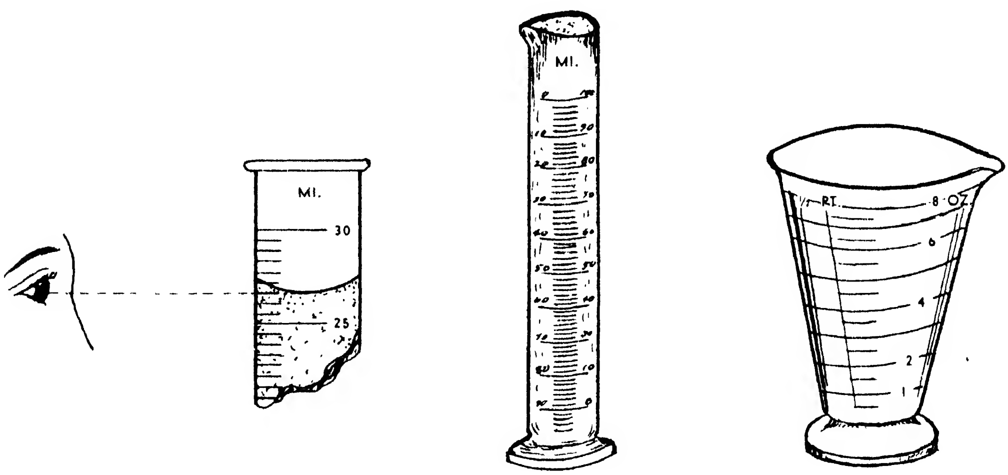


FIG. 11.

attraction for glass, the surface of the liquid in such a container is usually curved. This curved surface is called a "meniscus." The method for reading this meniscus is shown also in Fig. 11.

WEIGHT

Weight is the measure of the pull of gravity on an object. The most common unit of weight in the English system is the Avoirdupois pound (lb). This pound is divided into 16 ounces (oz), each ounce containing 437.5 grains (gr). The Troy pound, used by jewelers and goldsmiths, is divided into 12 ounces of 480 grains each. The short ton, consisting of 2000 lbs. is a larger unit of weight in the English system.

The metric unit of weight is the gram. It is the weight of one cubic centimeter of pure water at 4° centigrade. The gram is used with the usual metric prefixes when larger or smaller units of weight are desired. These units are shown in Table V.

METRIC UNITS OF WEIGHT

1 milligram	(mg)	=	.001	gram (g)
1 centigram	(cg)	=	.01	gram
1 decigram	(dg)	=	.1	gram
1 dekagram	(dkg)	=	10	grams
1 hectogram	(hg)	=	100	grams
1 kilogram	(kg)	=	1000	grams

TABLE V

It is often necessary or convenient to change English units into metric units, and vice versa. Table VI gives some of the more common equivalents.

METRIC — ENGLISH EQUIVALENTS

Metric		*English*
1 meter (m)	=	3.28 feet (ft.)
1 meter	=	39.37 inches
2.54 centimeters	=	1 inch
1 liter (l)	=	1.06 liquid quarts (qt)
28.35 grams	=	1 ounce (oz)
1 gram (g)	=	15.4 grains
1 gram	=	.035 ounce av.
1 kilogram (kg)	=	2.2 pounds
453.6 grams	=	1 pound av.

TABLE VI

Time is measured in seconds in both the English and Metric systems.

MEASURING AREA, VOLUME and DENSITY

Purpose:

1. To measure a rectangular block and calculate its (a) area and (b) volume.

2. To weigh this same rectangular block and calculate its density.

Introduction:

This experiment will give practice in linear measurement. The area of a rectangular surface is calculated by the formula $A = LW$, where A is area; L is length and W is width. Volume is the product of three dimensions, hence the formula $V = LWT$, T being the thickness in the case of a rectangular solid. Density is the weight of a unit volume, such as pounds per cubic foot or grams per cubic centimeter. Density is found by using the formula $D = \frac{W}{V}$, where W is weight and V is volume.

Tools and Materials:

Rectangular block of wood
Metric and English rule
Balance and set of weights

Procedure:

a) Area and Volume

Using an English rule and metric rule, measure accurately the three dimensions of a rectangular block of wood. Record these measurements in Table VII.

Kind of wood ....

	Length	*Width*	*Thickness*	*Volume*	*Surface Area*
English Units					
Metric Units					

TABLE VII

In the following space, calculate the area of the top, end, and side of the block.

ENGLISH UNITS			METRIC UNITS		
Top	*Side*	*End*	*Top*	*Side*	*End*

1. What is the total surface area of the block in square inches? ....In square centimeters? .... Record these in Table VII.
2. How many sides does a rectangular block have? ....
3. Write a formula for finding the surface area of a rectangular block. A = ...

   Calculate the volume of the rectangular block. Record these results in Table VII also.

VOLUME	
Metric Units	*English Units*

TABLE VIII

b) Weight and Density

Note— Weighing is done with platform or spring balances. See Fig. 12.

It should be understood that balances are delicate instruments and should always be given careful treatment.

If the double pan balance is used, a set of brass weights will also be needed. To weigh with these balances proceed as follows:

a) Place the object to be weighed on the left hand pan as you face the balance.

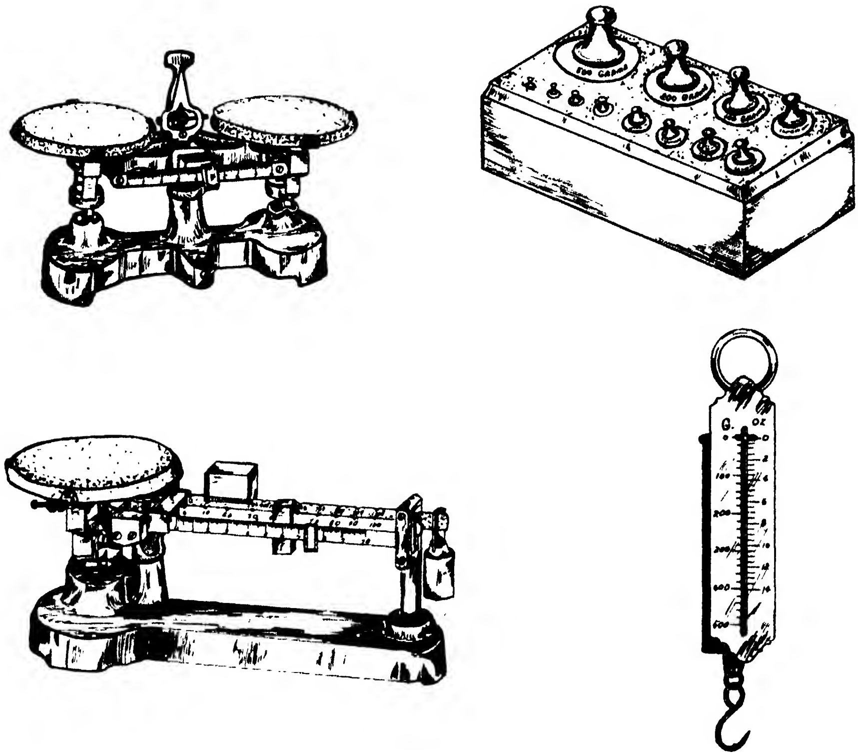


FIG. 12.

b) Place weights on the right hand pan until it is nearly in balance, then adjust the sliding weight until the pointer swings an even number of divisions on each side of the center line. Always keep the pointer swinging, as the beam may stick.

c) When in balance, add up all the weights on the right hand pan, and add to this sum the reading of the sliding weight.

d) Before leaving the balance, replace all the weights in their block and return the sliding weight to the extreme left end of the scale.

If the single pan balance is used, a block of weights is not needed, as the weighing is done by moving the sliding weights horizontally on the three beams of the balance. Proceed much as with the two pan balance, placing the object on the pan, then move the sliding weights, beginning with the heavier one, until the beam indicates a condition of balance. When in balance, add all the readings on the three beams, then return all weights to the extreme left, leaving the instrument ready for the next user.

Weigh the rectangular block used in part (a). Record the weights in Table IX.

	Weight	*Density*
English Units *		
Metric Units		

TABLE IX

***Note— If the weighing is done on a metric balance, convert to pounds by dividing by 453.6. Why?**

Using the formula for finding density, calculate the density of the wooden block in both English and metric units.

Record these results in Table IX.

Show your calculations in the space which follows.

DENSITY

English Units	*Metric Units*

Is density expressed in abstract or concrete numbers? ....

What does this mean? ....

New Words:

AVOIRDUPOIS.— (ăv'ẽr-dŭ-poiz') A system of weights. Meaning "goods of weight."

ALLOY.—A substance formed by mixing or combining two or more metals.

DENSITY.—The weight of a unit volume (cubic foot, cubic centimeter, etc.) of a substance. Density is always expressed in concrete numbers.

GRAIN.—A unit of weight in the English system derived from the weight of a grain of wheat.

MENISCUS.—The curved surface assumed by a liquid contained in a cylindrical vessel.

MERIDIAN.—An imaginary circle on the earth's surface which passes through the north and south poles.

Additional New Words:

____________ ....

....

____________ ....

....

____________ ....

....

PRECISION INSTRUMENTS

REFERENCES

Brown and Sharpe: *Catalog No. 34*, pages 10-15; 142-143.
Cornetet: *Methods of Measurement*, pages 20-34.
Holley and Lohr: *Mastery Units in Physics*, pages 12-14.
Smith: *Mechanics*, pages 14-18.
South Bend: *How to Run a Lathe*, page 390.
Starrett: *Handbook for Student Machinists*, pages 19-27.
War Department—
TM 10-590 *Hand, Measuring and Power Tools*, pages 89-106.

MICROMETER CALIPERS

Micrometer calipers, Fig. 13, make use of an exact screw thread for measuring more accurately than is possible with a ruler and spring calipers.

The English Micrometer has a screw with exactly 40 threads per inch. This screw revolves in a fixed nut so as to vary the opening between the measuring faces, one on the end of the spindle and the other on the anvil. The micrometer has a scale on the barrel and another on the thimble. The

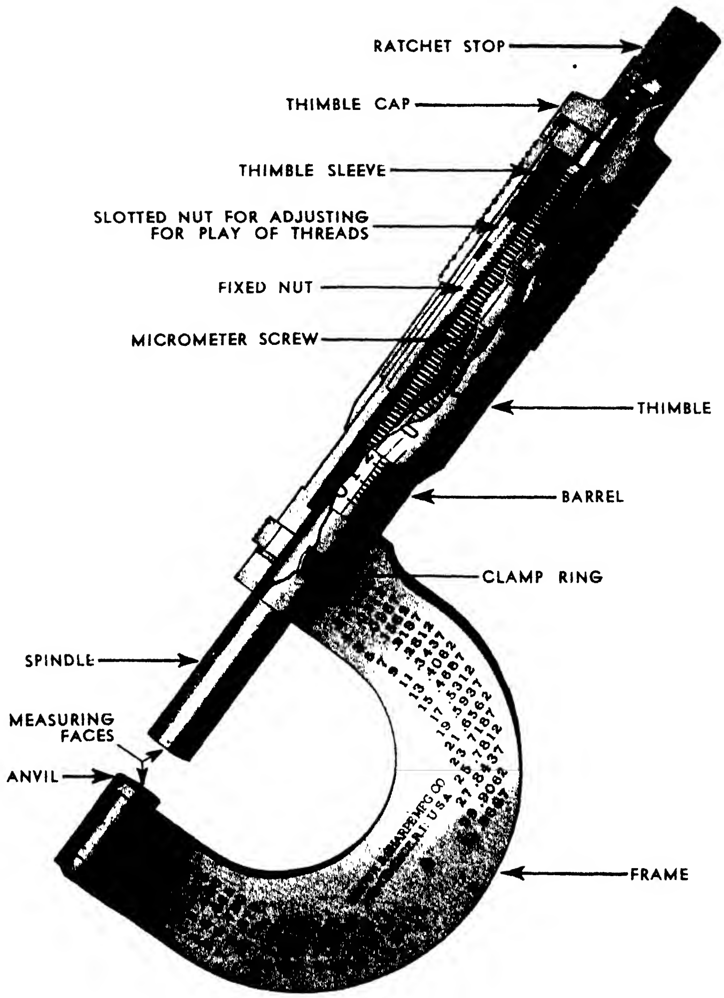


FIG. 13. MICROMETER (Courtesy, Brown & Sharpe Mfg. Co.)

numbers 1, 2, 3, etc. on the barrel, indicate hundreds of thousandths inches — .100, .200, .300, etc. The unnumbered lines between these represent .025 of an inch. The beveled edge of the thimble is graduated into 25 parts, each line indicating .001 inch. Every fifth line on the thimble is numbered, as 0, 5, 10, 15, and 20.

To read a measurement taken by a micrometer, add the reading of the graduations on the barrel which the thimble edge has passed, to that on the thimble which coincides with the long horizontal line on the barrel. Study Fig. 14 and Table X until you are familiar with the method of reading the English micrometer.

In Fig. 15 write the reading of the micrometer settings in the space provided below each diagram.

The *Metric Micrometer* is similar in construction to the one just studied. The screw thread used in the Metric Micrometer has 20 threads per centimeter. The barrel scale is divided into millimeters (sometimes

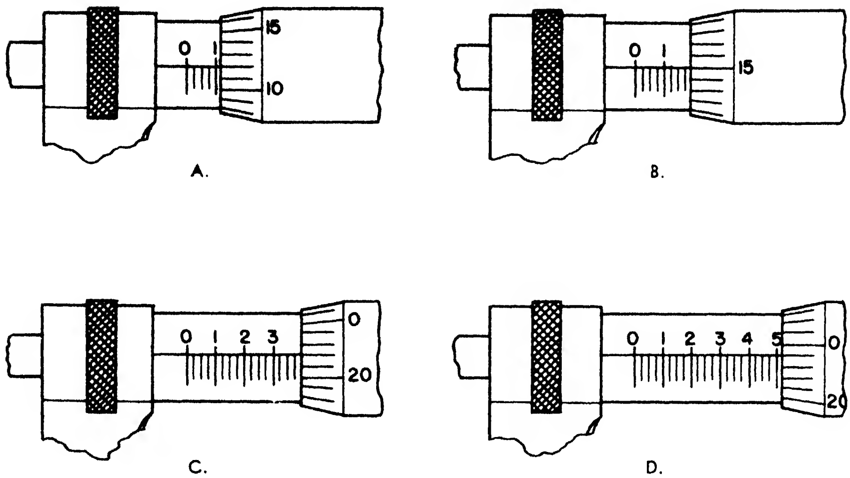


FIG. 14.

Example Number	*A*	*B*
Largest number visible on barrel	1 = .100	1 = .100
Lines visible between this number and the edge of the thimble	0 = .000	3 = .075
Lines on thimble which have passed longitudinal line on barrel	12 = .012	15 = .015
Reading of measurement — TOTAL	.112	.190

Example Number	*C*	*D*
Largest number visible on barrel	3 = .300	5 = .500
Lines visible between this number and the edge of the thimble	3 = .075	0 = .000
Lines on thimble which have passed longitudinal line on barrel	22 = .022	24 = .024
Reading of measurement — TOTAL	.397	.524

TABLE X

in half millimeters). These are numbered every 5th mm., as 5, 10, 15, etc. The thimble has 50 divisions, numbered in 5's as 0, 5, 10, 15, etc. Since the thimble makes two complete revolutions for each millimeter on the barrel, the divisions on the thimble represent 1/100 mm. This makes it necessary when reading a metric micrometer, to determine whether the thimble is on the first or second revolution.

Study Fig. 16 and Table XI until you understand how to read a metric micrometer. After you have learned to read a metric micrometer, place the reading of the micrometer settings shown in Fig. 17, below each diagram.

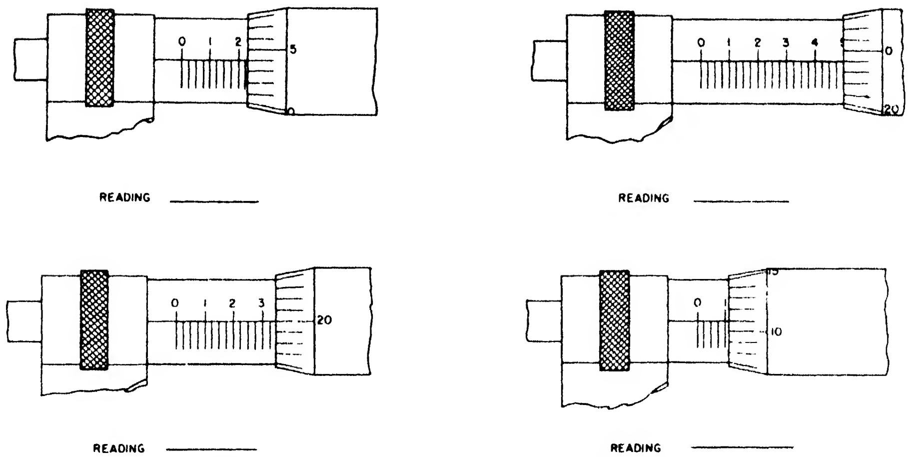


FIG. 15. ENGLISH MICROMETER READINGS.

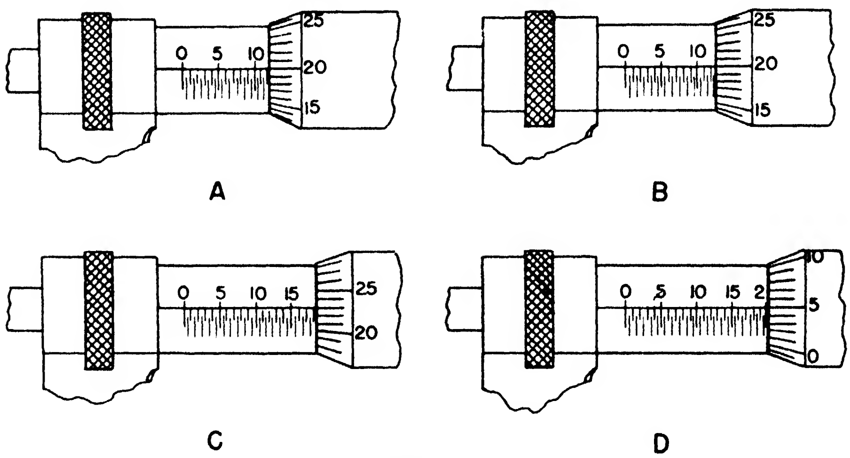


FIG. 16.

Example Number	*A*	*B*
Number of mm. visible on barrel	12 = 12.00	12 = 12.00
Lines on thimble which have passed the longitudinal line on barrel	20 = .20	20 = .20
Thimble on second turn, add 50	=	50 = .50
Reading of measurement — TOTAL	12.20	12.70

Example Number	*C*	*D*
Number of mm. visible on barrel	18 = 18.00	20 = 20.00
Lines on thimble which have passed the longitudinal line on barrel	23 = .23	5 = .05
Thimble on second turn, add 50	=	=
Reading of measurement — TOTAL	18.23	20.05

TABLE XI

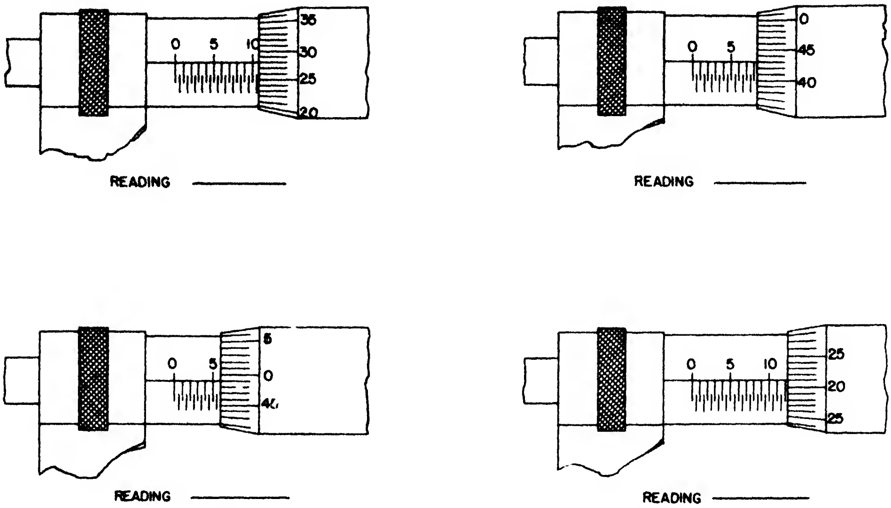


FIG. 17. METRIC MICROMETER READINGS.

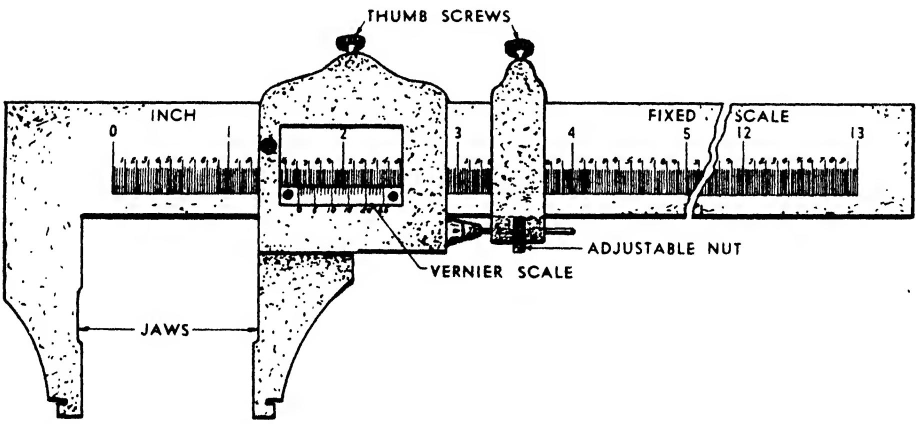


FIG. 18. VERNIER CALIPER.

VERNIER CALIPERS

Vernier calipers are used to make accurate measurements because it is easier to judge the coincidence of two lines than it is to estimate the distance between two scale divisions.

Fig. 18 shows a vernier caliper which measures to .001 of an inch. The fixed scale is divided into inches (large numbers), tenths of inches (small numbers) and fortieths of inches (unnumbered divisions). The sliding or vernier scale contains 25 divisions. Since these cover only 24 divisions of the fixed scale, it is possible to divide each unnumbered division on the fixed scale into 25 parts, or to .001 of an inch. Study Fig. 19 and Table XII carefully, to understand how this caliper is read.

Other vernier calipers are available in the English system which read

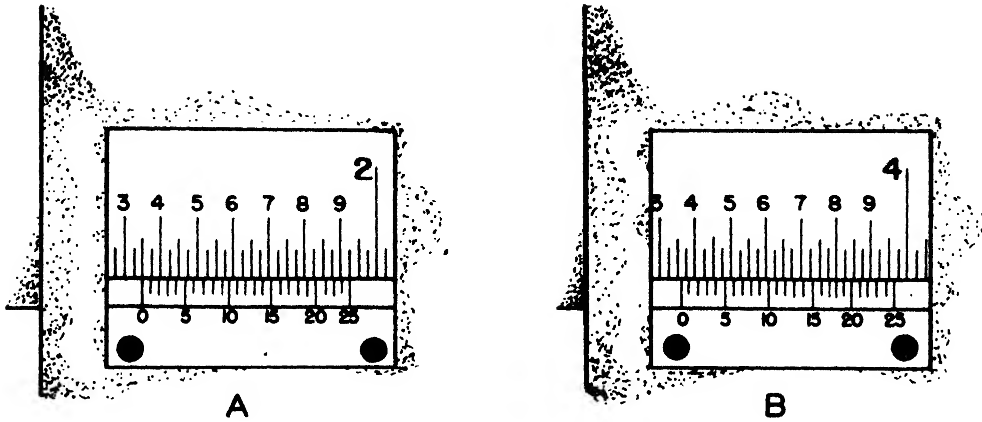


FIG. 19. EXAMPLES OF VERNIER CALIPER SETTINGS.

Example	*A*	*B*
Number of inches 0 has passed	1 = 1.000	3 = 3.000
Number of tenths 0 has passed	3 = .300	3 = .300
Number of fortieths 0 has passed	2 = .050	2 = .050
Coinciding Vernier line	0 = .000	18 = .018
Reading of Caliper — TOTAL	= 1.350	= 3.368

TABLE XII

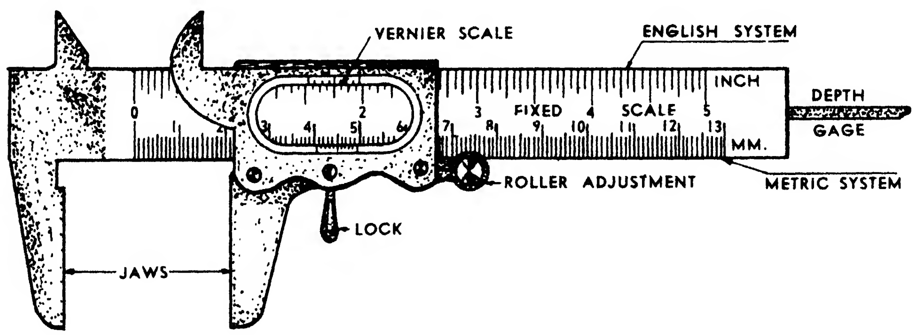


FIG. 20.

to the 1/128 of an inch or in the metric system which read to the tenth of a mm. (See Fig. 20).

The upper fixed scale Fig. 21, is divided into inches and sixteenths. The vernier has 8 divisions, each being 1/128 of an inch. Study Fig. 21 and Table XIII to understand how this vernier is read.

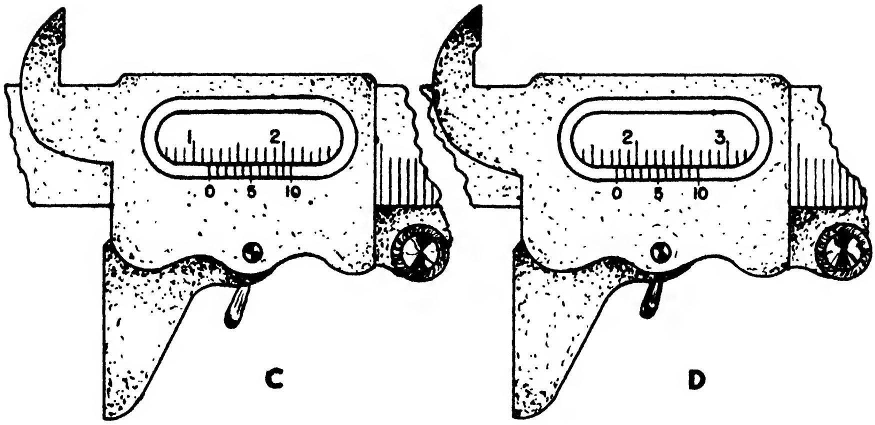


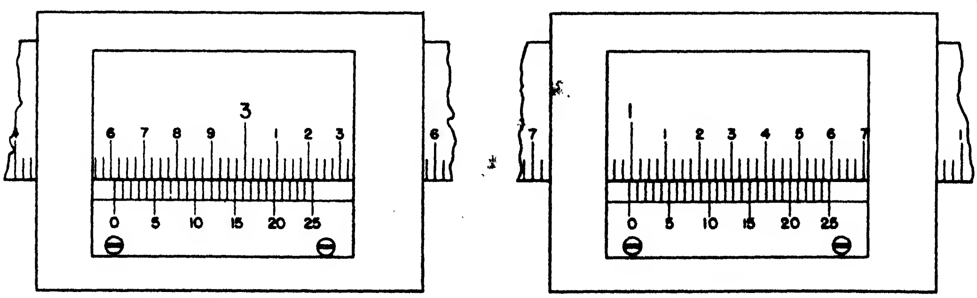
FIG. 21.

Example	*C*		*D*	
		128		128
Number of inches 0 has passed	2 = 2	00	0 = 0	00
Number of sixteenths 0 has passed	0 = 0	00	8 = 0	64
Coinciding line on vernier	5 =	05	6 = 0	06
Reading of Caliper — TOTAL	2	$\frac{5}{128}$	0	$\frac{70}{128}$
Reading with fraction reduced	2	$\frac{5}{128}$		$\frac{35}{64}$

TABLE XIII

Example Number	E	F
Number of centimeters 0 has passed	1 = 1.00	1 = 1.00
Number of millimeters 0 has passed	1 = .10	7 = .70
Coinciding line on vernier	9 = .09	7 = .07
Reading of Caliper — TOTAL	1.19	1.77

TABLE XIII A



READING ________ READING ________

FIG. 22A. VERNIER READINGS.

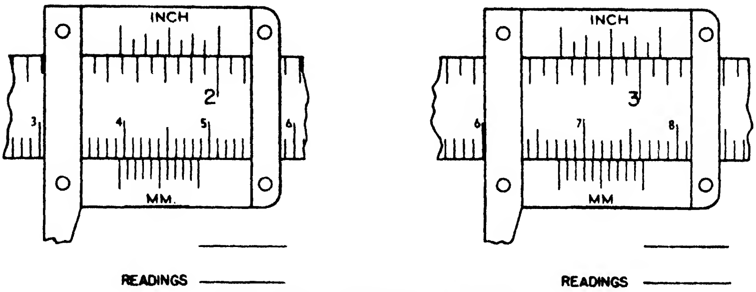


FIG. 22B. VERNIER READINGS

When the reading of the verniers previously described has been mastered, read each of the settings shown in Fig. 22, recording the readings in the space provided beneath each diagram. Be sure to state whether the reading is in inches or centimeters.

MEASURING WITH MICROMETER AND VERNIER CALIPERS

Purpose:

1. To measure objects with micrometer and vernier calipers.
2. To calculate the volume and density of the objects measured.

Tools and Materials:

Micrometer Calipers (English and metric)
Balance and weights
Steel ball bearing
Steel cylinder

Procedure:

Measure the diameter of a ball bearing with a micrometer caliper. Measure the diameter and length of a steel cylinder with a vernier caliper. Weigh both the ball bearing and cylinder. Record all this information in Table XIV.

	BALL BEARING			CYLINDER		
	Diameter	*Radius*	*Wt.*	*Diameter*	*Length*	*Wt.*
English Units						
Metric Units						

TABLE XIV

Using the information in Table XIV and the proper formulas, calculate the volume of the ball bearing and the cylinder. Show calculations in the following spaces.

BALL BEARING - VOLUME	
English Units	*Metric Units*

CYLINDER - VOLUME	
English Units	*Metric Units*

Using the proper formulas, calculate the density of the ball bearing and cylinder. Show your calculations in the following spaces.

BALL BEARING - DENSITY	
English Units	*Metric Units*

CYLINDER - DENSITY	
English Units	*Metric Units*

How do the densities of the ball bearing and cylinder compare? ....

....

THEORY OF MACHINES

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 43-45; 217-227.
Dull: *Modern Physics*, pages 107-112; 163-167; 170-173.
Fletcher: *Unified Physics*, pages 143-147; 163-175.
Holley and Lohr: *Mastery Units in Physics*, pages 135-138; 197-203.
Millikan and Gale: *New Elementary Physics*, pages 149-151; 171-177.
Smith: *Mechanics*, pages 30-34; 89-93; 100-104.
War Department—
TM-10-570 *The Internal Combustion Engine*, pages 8-10.
TM-10-585 *Automotive Power Transmission*, page 28.

Machines are an essential part of modern civilization. Man, in his conquest of nature, has found it necesary to supplement his energies with devices that will multiply force and increase the speed of action.

Man has always been alert to the possibilities of machines as a means of self protection and increasing personal comfort. With the aid of machines, great tracts of land have been brought under cultivation, making it possible for one person to produce the food for many. By means of machines it is possible to transport this food many miles in a few hours, fresh and wholesome.

Machines have enabled man to erect large buildings, factories, and homes. They have helped him to span great distances by means of a mod-

ern system of highways, skyways and railroads. Many other things have been accomplished by the use of machines that would have been impossible had man been forced to rely only on his own physical strength.

Machines are used to obtain from the earth the raw materials which supply the needs of commerce. Other machines produce an endless stream of goods necessary to our comfort, amusement, travel and protection.

Man is ever seeking new machines to produce food, to manufacture and distribute goods, to lighten burdens, to carry loads, and to add to his comfort and enjoyment of life.

Machines have enabled man to utilize energy efficiently. A machine is a device for transforming or transferring energy. Furnaces convert the chemical energy of fuel into heat energy. Motors transform the chemical energy of oil into mechanical motion for useful work. Great turbines, turned by the energy of falling water, drive generators that produce electrical energy. This electrical energy is then transported by transmission lines to distant cities and factories to do work. Man is always improving machines so that they will utilize the greatest amount of energy from the least amount of fuel; obtain the greatest amount of work with the least effort.

ENERGY

Energy is the capacity for doing work. Energy exists in many forms. It may be mechanical, electrical, or chemical; or it may manifest itself as light or heat. Energy can not be created or destroyed but it can be changed from one form to another. Thus coal, containing chemical energy, can be burned (oxidized), to produce heat energy. This heat energy may then be used to produce steam for operating a turbine (mechanical energy), which in turn operates an electrical generator (electrical energy). The electrical energy thus produced can be transformed again into heat, light or motion. In the storage battery chemical energy is changed into electrical energy. An electrical generator changes mechanical energy into electrical energy. A photo-electric cell (electric eye) changes light energy into electrical energy, while a thermocouple converts heat energy into electrical energy.

Transformations of energy are never 100% efficient because some energy is lost, usually in the form of heat.

Energy is also classified as "potential" and "kinetic." Potential energy is energy of position, while kinetic energy is energy of motion.

Potential energy may exist in several forms. An up-raised hammer has a potential ability to do work because of its position. The amount of work it can do depends upon the weight of the hammer and the height to which it has been raised.

A body in a strained position possesses potential energy. After a clock spring is "wound" it drives the gear wheels of the clock as it uncoils. The strain within it is due to its changed shape. Within the elastic limit of the material, there is stored in a deformed body an amount of energy equal to the external work done upon it, assuming no work is expended in producing heat.

The chemical energy stored in coal, oil, and gas is a form of potential energy, having the ability to do work. Chemical action releases this energy.

The energy of the water above a falls has great capacity for doing work by acting on turbine wheels. These examples are common types of energy which are termed potential.

As the hammer of a steam hammer drops, (Fig. 23) its potential energy changes into energy of motion. When the hammer hits the hot metal, all of its potential energy has been changed to kinetic energy. This energy is proportional to the weight of the body and to the square of its velocity.

$$\text{Kinetic Energy} = \frac{WV^2}{2g}$$

When the weight (W) of the body is measured in pounds, the velocity (V) in feet per second and the acceleration of gravity (g) in feet per second

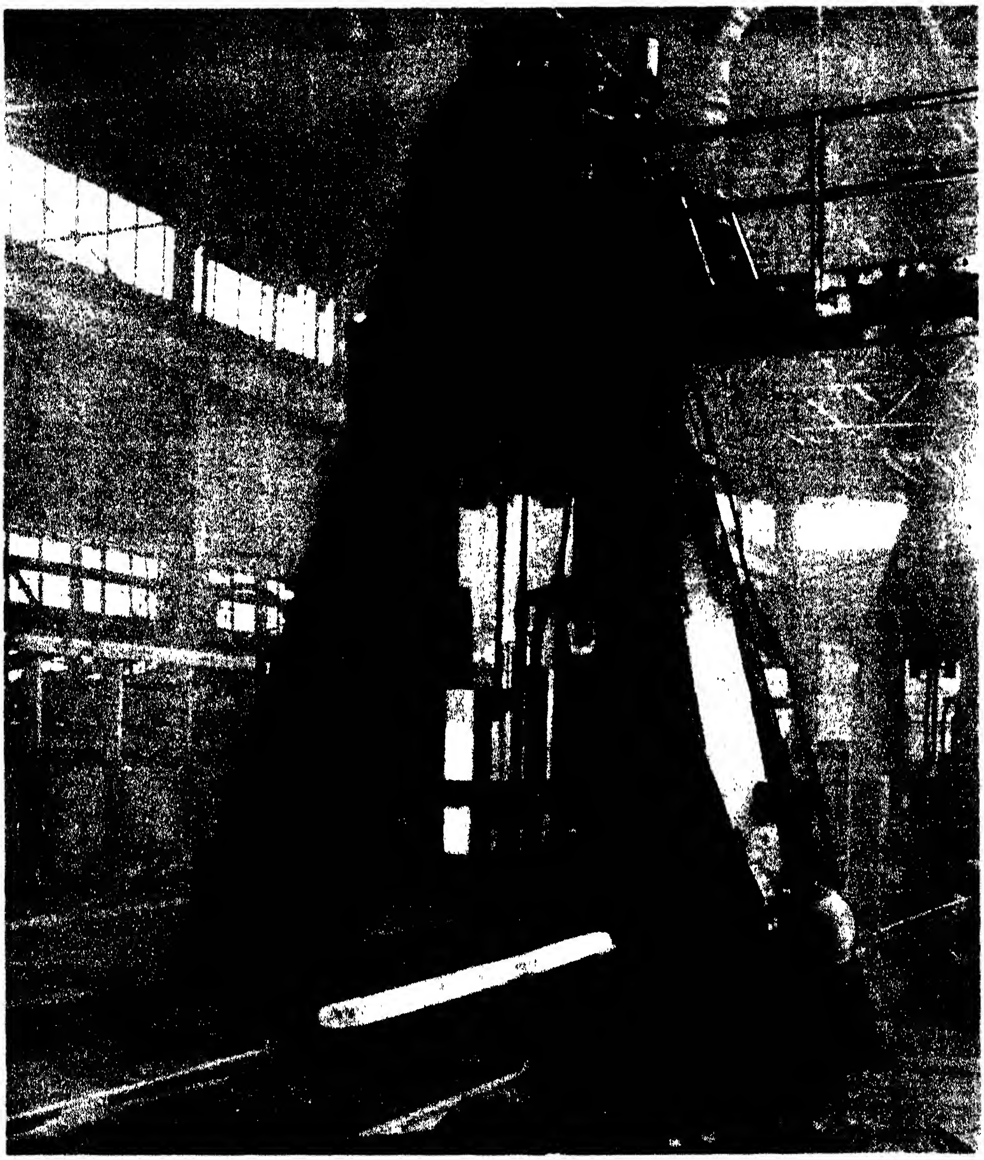


FIG. 23. EIGHT TON HAMMER FORGING BLOOMS.

per second, the kinetic energy will be in foot pounds. This formula expresses the work a moving body will do upon impact with another body.

FORCE

A force, defined as a "push or a pull," changes or tends to change the state of motion of a body. There are several kinds of force. The force of gravity causes water to run down hill. The force of gravitation causes two bodies to be attracted toward one another. The force exerted by a man pulling on a rope is an example of physical force. A motor driving a fan is an example of mechanical force. Forces may tend to compress, bend, pull apart, cut in two, or change the shape of a body. A force may also cause a body to move faster or slower by changing its velocity.

Ordinarily force is measured in grams and pounds. These are called *gravitational units*. In engineering work, force units which are not dependent on the pull of gravity, are used. These are known as *absolute units*. The *dyne* and *poundal* are absolute units of force.

WORK

The word "work" has a special meaning in mechanics, differing from the ordinary interpretation of the word. Energy is the capacity for doing work and is expended by exerting a force. To accomplish work, a force exerted on a body must move that body through a given distance.

Since force is measured in pounds or grams and distance measured in feet or centimeters, work is the product of a force (in pounds or grams) and distance (in feet or centimeters).

$$\text{Work} = \text{Force} \times \text{Distance}$$
$$W = F \times D$$

For example, if a sack of sugar weighing 25 lbs. is lifted from the floor to the table, a distance of 3 feet, the work done is 25 lbs x 3 feet = 75 ft. lbs. Thus work is done in lifting the sugar from the floor to the table.

In any situation, the amount of work done is the product of the force required to move the body and the distance the body is moved.

New Words:

ABSOLUTE UNITS.—Units of measure that are independent of gravitational forces; the dyne and poundal.

ACCELERATION.—Gain in speed or velocity per second. Expressed as feet or centimeters per second per second.

ELASTIC LIMIT.—The limit to which a body may be deformed and still resume its former position when the stress is relieved.

ENERGY.—The ability to do work.

FUEL.—A substance that supplies heat energy when oxidized.

GRAVITATION.—The mutual attraction between any two bodies in space.

GRAVITY.—The attraction of the earth for a mass.

IMPACT.—The single instantaneous stroke of a body in motion against another either in motion or at rest.

KINETIC ENERGY.—The energy of motion. The ability of a moving body to do work.

OXIDIZED.—To be combined with oxygen, as in a combustion or a chemical reaction.

PHOTO-ELECTRIC CELL.—A vacuum tube whose ability to conduct electricity is modified by the action of light.

POTENTIAL ENERGY.—The energy possessed by a body due to its position or strain.

STRAIN.—A deformation or distortion due to stress or force. A change in form or size.

STRESS.—A force, acting on a body, tending to deform it. A force causing shear, tension, torsion, bend or compression.

THERMOCOUPLE.—A device composed of two dissimilar metals welded together at a given point. Any change in temperature at this point, causes an electric current to flow around the circuit connecting their free ends.

VELOCITY.—Rate of motion. Expressed as miles per hour (m.p.h.) or feet per second.

Additional New Words:

________________ ....

....

________________ ....

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WORK AND ENERGY

Purpose:

1. To understand the meaning of "work" and to learn the units by which it is measured.
2. To distinguish between "potential" and "kinetic" energy.

Tools and Materials:

Heavy weight	Model drop hammer
Board, 3′ long x 8″ wide	Nail
Spring balance (30 lb)	Block of white pine

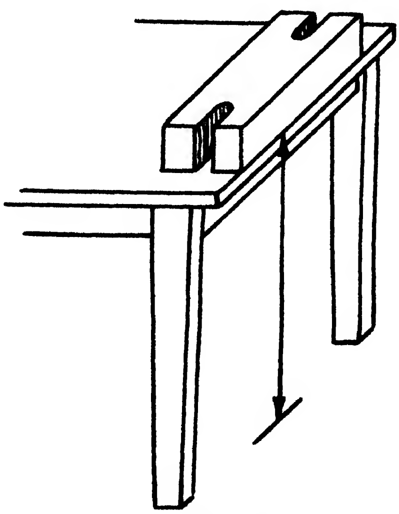

FIG. 24.

Procedure:

a) Work and Energy

Place a wide board on the laboratory table so that the weight to be used will not scratch the table top. Using a spring balance, weigh some heavy object. Measure the distance from the floor to the top of the board on the table. Record these measurements in Table XV.

Carefully lift the weight from the floor to the board on the table. (Fig. 24.) Calculate the amount of work done in lifting the weight.

Weight of object ....________ lb.________ kg.
Height of table ....________ ft.________ m.
Work (force x distance) ....________ ft. lb.________ kg.m.

TABLE XV.

Now drag the weight slowly along the board by means of the spring balance. Read the balance to determine the force necessary to move the weight, and measure the distance it was moved. Calculate the work done in sliding the weight, recording all information in Table XVI.

Force required to slide weight	______	lb.	______	kg.
Distance wt. is moved	______	ft.	______	m.
Work done (force x distance)	______	ft. lb.	______	kg.m.

TABLE XVI

1. The work done in lifting the weight to the table was stored in the weight as (kinetic, potential) .... energy.
2. In sliding the weight it (was, was not) .... lifted, therefore (more, no more) .... potential energy was stored in it. (More, no more, less) ....work is done in dragging the weight than in lifting it.
3. Energy of motion is called .... energy.

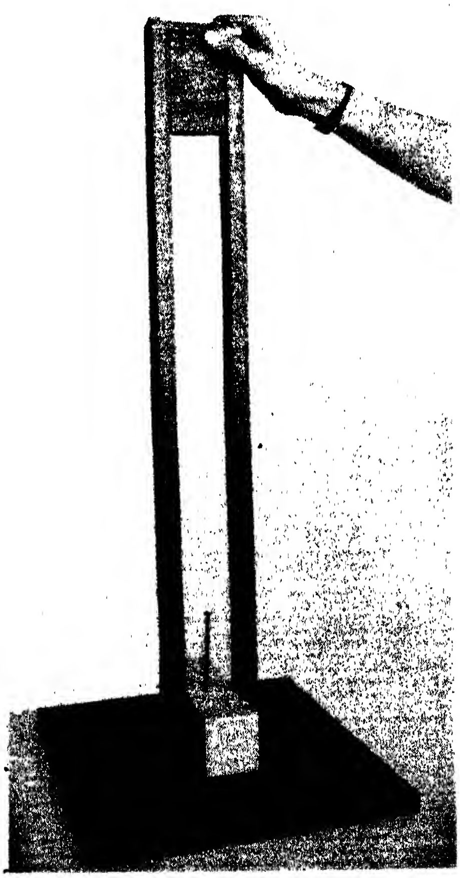

FIG. 25. SMALL DROP HAMMER

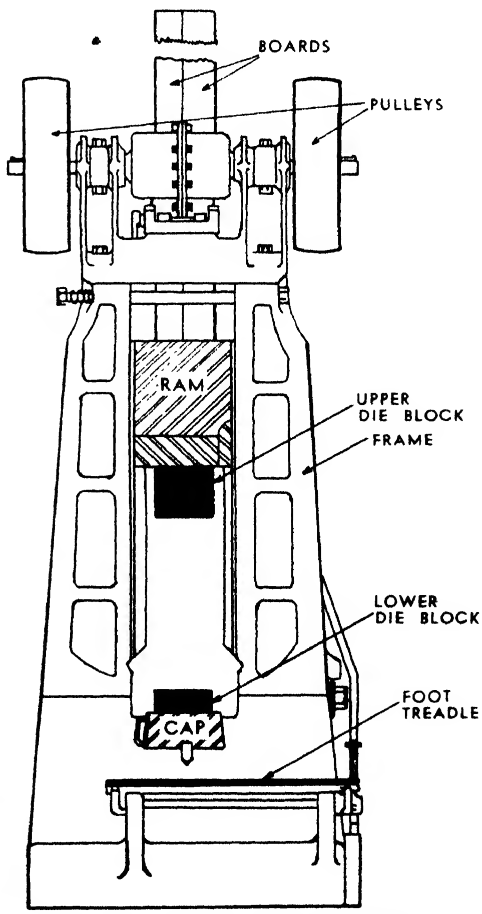

FIG. 26. BOARD DROP HAMMER.

b) Force of a blow

Note: When a weight, such as a pile driver or drop hammer is raised to a given height, the potential energy (measured in foot pounds) stored in it, is found by multiplying the weight by the height to which it has been lifted. When this weight is dropped, the force of the blow it delivers is measured in pounds and is calculated by the formula

$$\text{Force of blow} = \frac{W\ H}{d} + W$$

W = weight; H = height (in feet) from which the weight falls; d = distance in feet the object struck is moved or penetrated. Start a nail in a block of white pine, then place it under the hammer of a small drop hammer. See Fig. 25. Measure accurately the height of the nail head (in feet) above the wood, then raise the hammer as high as possible above the nail.

Measure accurately (in feet) the distance from the nail head to the bottom of the hammer. Drop the hammer and measure the distance (in feet) the nail is driven into the wood. Place the information in Table XVII and complete the calculations called for.

Weight of hammer ____________ lb.	
Distance hammer fell __________ ft.	Original ht. of nail __________ ft.
Potential energy of hammer ____ ft. lbs.	Final height of nail __________ ft.
Kinetic energy of hammer ______ ft. lbs.	Distance nail moved __________ ft.

TABLE XVII

CALCULATIONS

$$\text{Force of blow on nail} = \frac{W\ H}{d} + W$$

$$=$$

Questions and Problems:

1. (Kinetic, potential) .... energy is stored in the drop hammer when it is raised to the top of the slide. When the hammer strikes the nail, all of the .... energy stored in it is changed into .... energy.
2. Work is defined as the product of .... and .... while energy is ....
3. The English unit most commonly used to measure work is the ....while the metric unit is the ....

4. An object weighs (more, less) ....at the north pole than it does at the equator. The pound and gram are (gravitational, absolute) .... units of force. The mass of an object does, does not) .... change at different places on the earth's surface.

Mass is ....of matter while weight is ....

....

5. Potential energy is measured in foot pounds, gram centimeters, foot poundals and ergs. The formulas for finding potential energy in each of these units are as follows:

In foot pounds and gram centimeters, P. E. =

In foot poundals and ergs P. E. =

6. One foot pound equals .... foot poundals; one gram centimeter equals .... ergs.

7. The formula for finding kinetic energy in foot pounds or gram centimeters is:

K. E. = ft. lbs. or g. cm.

In foot poundals and ergs, kinetic energy is found by the following formula:

K. E. = foot poundals or ergs.

8. *a)* It is 29 feet from the ground floor to the third floor of a building. Calculate the amount of work you would do in climbing the steps from the ground to the third floor. Your weight is .... pounds.

b) How much potential energy would you possess because of the amount of work done in climbing these steps?

1. ....foot pounds 2. ....Kilogram meters

9. The law of conservation of energy states that energy cannot be .... or .... but can only be ....

....

10. The ram of a "board drop hammer" Fig. 26, weighs 800 pounds and the die weighs 168 pounds. The stroke of the hammer is 3 feet.

a) How much potential energy is stored in the ram and die block when they are raised to the top of the frame?

b) If a 1″ iron rod is flattened to ½″ when the die falls, what is the force of the blow?

POWER

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TM 10-585, *Automotive Power Transmission*, pages 28-29.

POWER

To be able to distinguish between "work" and "power" is important. Some machines are more powerful than others because they can do more work in the same amount of time. For example, a large truck can move one ton of coal up a hill 100 feet high in three minutes while a smaller truck will require nine minutes to do the same job. The amount of work done by both trucks is the same but the power of the larger truck is three times that of the smaller one because it required only one-third as much time. Hence, the term power adds the element of time.

POWER IS THE TIME RATE OF DOING WORK

The mechanical unit of power is the "horsepower." It is work done at the rate of 33,000 foot pounds per minute or 550 foot pounds per second.

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Foot pounds}}{\text{Time}}$$

$$\text{Horsepower} = \frac{\text{Foot pounds per minute}}{33{,}000}$$

$$= \frac{\text{Foot pounds per second}}{550}$$

Mechanical power is the rate at which mechanical energy is expended and is independent of the total work to be done.

HORSEPOWER IS DETERMINED BY THREE METHODS

1) The brake absorption method. (Brake Horsepower.) The prony brake (Fig. 27) is used to determine the horsepower of a motor. By this

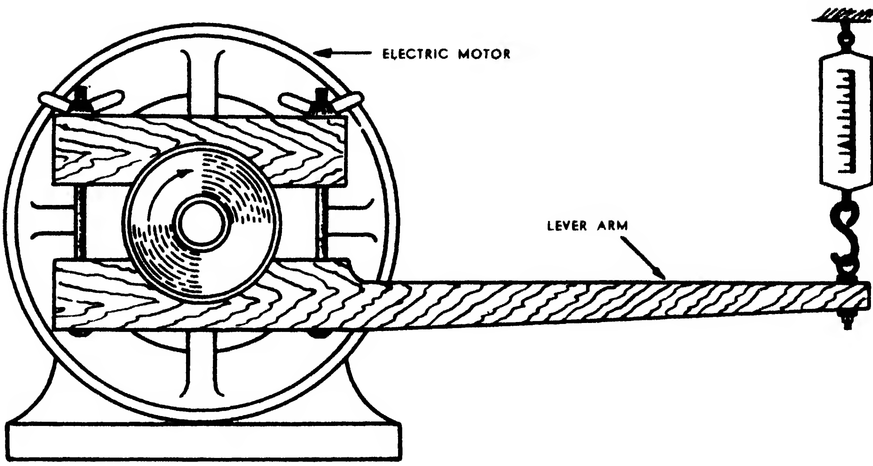

FIG. 27. PRONY BRAKE.

method, the mechanical energy of a rotating wheel or pulley is transformed into heat. The work done is calculated by multiplying the length of the lever arm, r (in feet, 2π, the r.p.m. and the force exerted on the balance (in pounds). Dividing this product by 33,000 gives the H.P. rating of the motor or engine. An experiment will be performed to demonstrate this method.

2) S.A.E. (Society of Automotive Engineers) horsepower. This is an arbitrary method of calculating horsepower and is used for comparative purposes such as determining the amount to be paid to the state for a license fee. The formula for determining S.A.E. horsepower is

$$\text{H.P.} = \frac{D^2N}{2.5}$$

Where D = the bore of the cylinder in inches
N = the number of cylinders
2.5 = a constant

3) Indicated horsepower (I.hp.). This method is used almost exclusively for determining the H.P. of steam engines. It can also be used for internal combustion engines with a slight alteration. I.hp. always exceeds the brake horsepower as it makes no deductions for frictional losses. The formula for finding I.hp. of a steam engine is

$$\text{I.hp.} = \frac{PLAN}{33{,}000}$$

For an internal combustion engine

$$\text{I.hp.} = \frac{PLANK}{33{,}000}$$

where
P = the average effective pressure in pounds per square inch
L = the length of the stroke in feet
A = the area of the piston head in square inches
N = the number of power strokes per minute
K = number of cylinders

Most steam engines, Fig. 28, have double acting pistons. In figuring their H.P., the head and crank ends must be figured separately and then

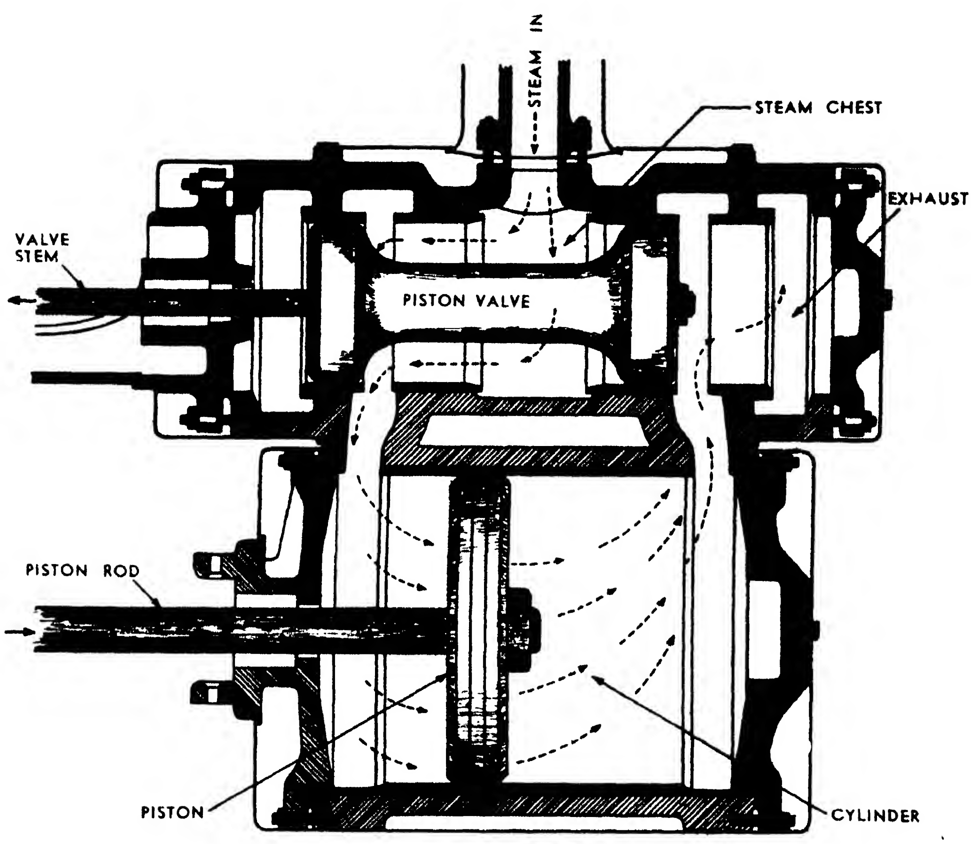

FIG. 28. STEAM ENGINE.

added together to obtain the total horsepower. This is necessary in order that the area of the space taken up by the piston rod may be subtracted from the area of the piston on the crank end. In a 4-stroke cycle internal combustion engine, N = r.p.m./2; in a 2-stroke cycle engine, N = r.p.m.

MECHANICAL EFFICIENCY

The mechanical efficiency of an engine is the ratio of its brake horsepower to its indicated horsepower.

$$\text{M.E. (mechanical efficiency)} = \frac{\text{Brake H.P. (transmitted)}}{\text{Indicated H. P. (developed)}}$$

THE HORSEPOWER OF AN ELECTRIC MOTOR

Purpose:

To use the prony brake in determining the brake horsepower of an electric motor.

Tools and Materials:

Small electric motor
Prony brake
Watch
Spring balance
Speed counter

Introduction:

To calculate the H.P. of a motor, it is necessary to find the number of foot pounds of work it will do in one minute, then divide by 33,000. Why?

With the prony brake, the torque or turning force developed by a motor is determined by multiplying the force exerted (in pounds) by the length of the lever arm (in feet). Having this information, the H.P. developed can be computed by the formula

$$\text{H.P.} = \frac{2\pi r \text{ x r.p.m. x } F}{33{,}000}$$

where r = length of the lever arm from the center of the shaft
F = force or pull exerted on the lever arm in pounds.

Procedure:

Set up the prony brake as shown in Fig. 27. Start the motor with the brake shoes loosened, then gradually tighten the brake shoes until the motor is under load. Read the spring balance. With a speed indicator and watch, determine the r.p.m. of the motor. Measure the length of the lever arm from the center of the shaft to the center of the screw eye.

RECORD

Length of lever arm .... ft.	r.p.m.	Balance reading ....

TABLE XVIII

Using the data obtained and the H.P. formula, calculate the H.P. of the motor. Show your calculations in the following space.

Questions and Problems:

1. Power is the .... of doing work.
2. Three factors used in determining power are ....
   .... and ....
3. One horsepower is work done at the rate of .... ft. lb. per minute or .... ft. lb. per second.
4. The metric unit of power is the .... It is the work done at the rate of .... joule, or ....ergs per second.

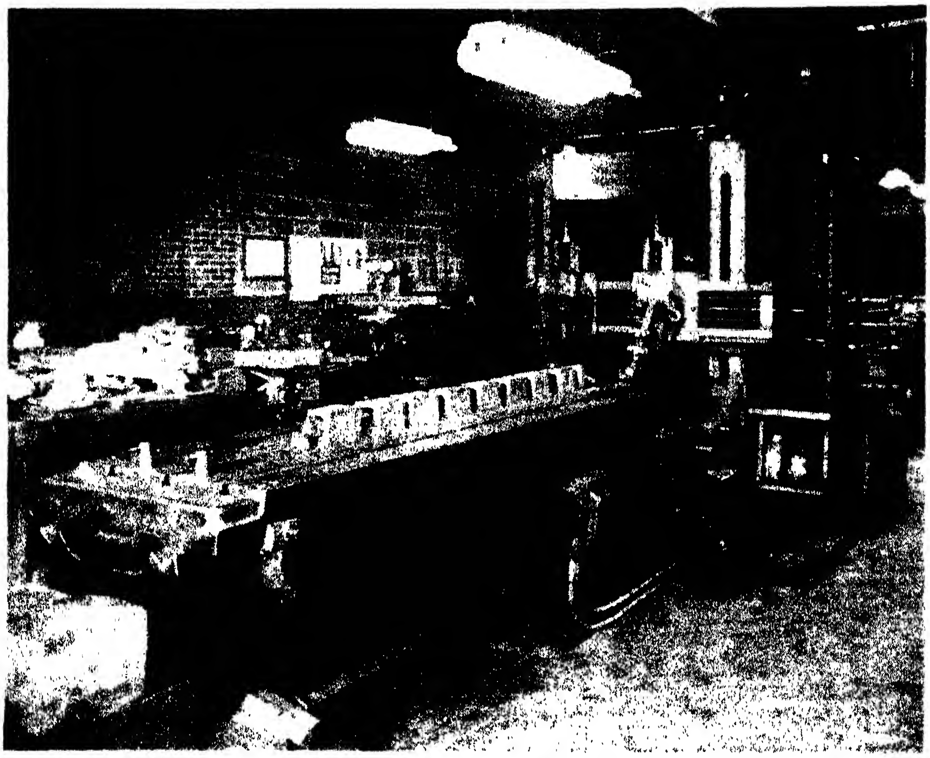

FIG. 29. A METAL PLANER.

5. A kilowatt is .... watts. A horsepower is equal to .... watts.

6. In driving a metal planer such as shown in Fig. 29, the difference in tension between the two sides of the belt is 40 pounds. The belt is traveling at the rate of 2500 feet per minute. What horsepower is being transmitted?

7. A six cylinder automobile motor develops 85 H. P. when operating at 40 m.p.h. If the cylinders are $3\frac{5}{8}''$ bore, what is its S.A.E. horsepower rating?

8. In determining the brake horsepower of a gasoline motor with a prony brake the balance reading is 50 pounds, the length of the lever arm is 5 feet and the r.p.m. is 850. Compute the brake horsepower of the motor.

9. In calculating the horsepower of a reciprocating steam engine the following information was obtained. Mean effective pressure, 35 pounds per square inch, length of stroke, 24 inches, diameter of piston, 16 inches, diameter of piston rod, 3.5 inches, r.p.m. 200. Find the I.hp.

10. A two-stroke cycle Diesel engine has six cylinders, each with $4\frac{5}{8}''$ bore and $5\frac{1}{2}''$ stroke. The average combustion pressure is 89 pounds per square inch and the r.p.m. is 1920. Find the I.hp. (Note—with a two-stroke cycle engine, the piston furnishes a power stroke for each revolution of the crankshaft).

11. A steam engine developing 225 H. P. transmits 190 H. P. Find its mechanical efficiency in percent.

12. An engine is transmitting 110 H. P. Its M. E. is 88%. What power does it develop?

POWER (Pulleys and Belts)

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  Gates Rubber Co.: *V-Belt Drives*.
  Dayton Rubber Co.: *Cog Belt Drives*.

PULLEYS

A simple method of transmitting power is by means of belts and pulleys. The pulley acts as a modified lever (see Fig. 30) for transferring energy and may be used to increase, decrease or retain the same speed

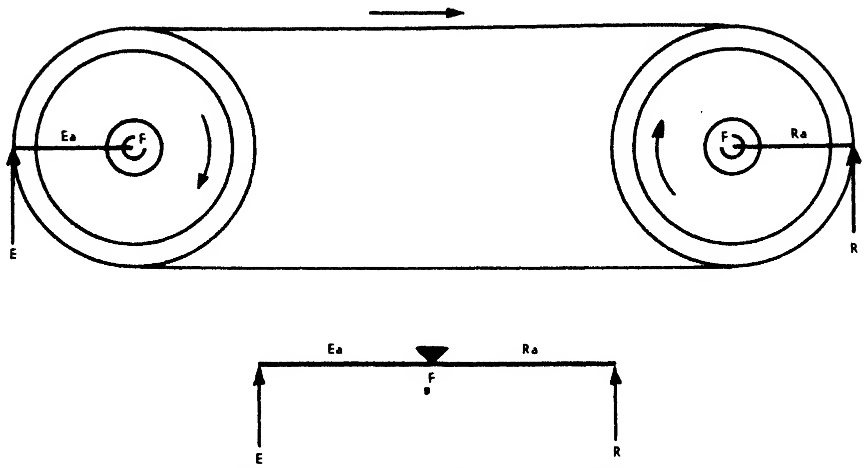


FIG. 30. A PULLEY ACTS AS A LEVER.

as that of the effort. It may also be used to change the direction in which the force acts. Fig. 31A shows two pulleys of the same diameter connected

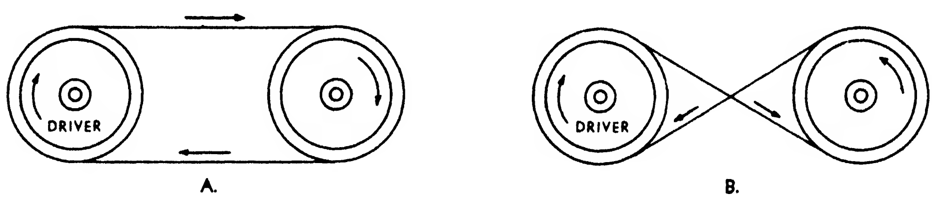


FIG. 31. DIRECTION AND SPEED OF PULLEY.

with an endless belt. No change of speed occurs but when the belt is crossed, as in Fig. 31B, the direction of rotation is reversed. By using pulleys with different diameters, the speed of rotation can be changed.

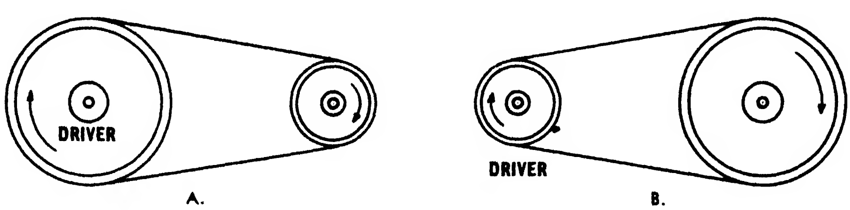


FIG. 32. CHANGE IN SPEED OF PULLEY.

Fig. 32A shows the arrangement for increasing the speed of rotation while Fig. 32B shows how speed can be reduced. From this it is seen that the *number of revolutions a pulley makes is inversely proportional to the diameter.* The smaller the diameter the greater the speed.

Pulleys for use with flat belts may be made of cast iron, wood or steel. Cast iron pulleys should not be operated at more than 85 feet per second,

rim speed, while steel pulleys may be operated safely at slightly higher speeds. Pulleys which operate at high speeds should be accurately balanced. Semi-steel is preferred for V-belt pulley sheaves because its close grained structure provides a smooth groove surface. V-belt pulleys are also made of pressed steel. Pulleys for flat belts, Fig. 33, are usually

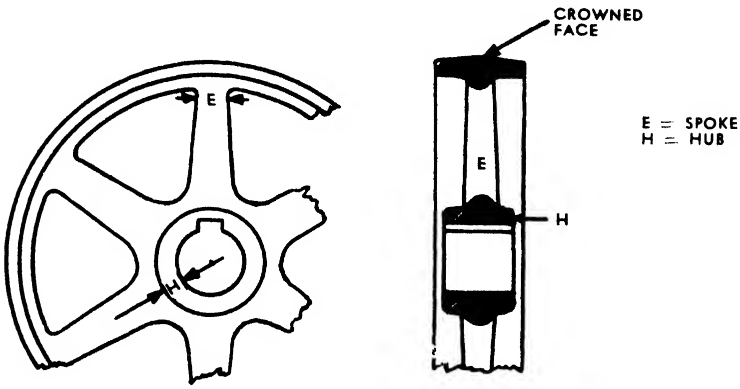
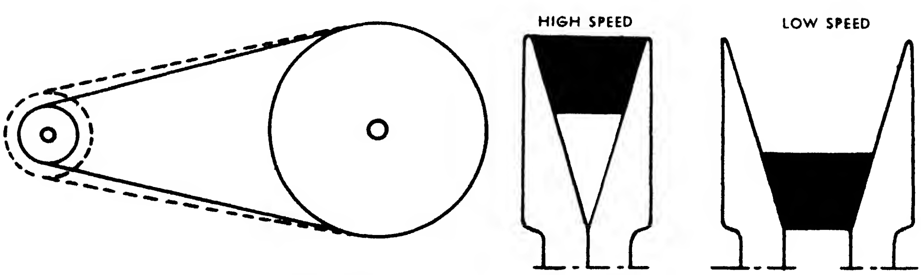


FIG. 33. CROWNED PULLEY.

FIG. 34A.



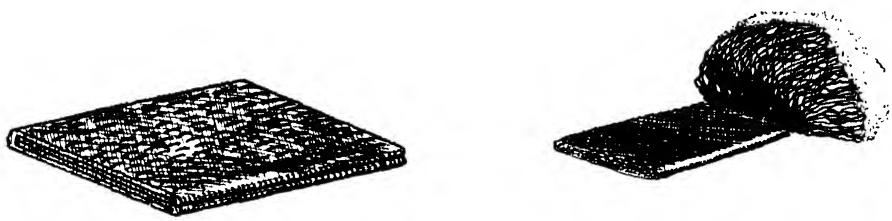
VARIABLE PITCH SHEAVE FOR INCREASING OR DECREASING SPEED

FIG. 34B. VARIABLE PITCH SHEAVE FOR INCREASING OR DECREASING SPEED.

"crowned" to aid in preventing the belt from running off the wheel. Fig. 34A shows correct and incorrect methods of fitting V-belts. Fig. 34B shows a variable speed V-belt sheave.

BELTS

Belts transmit power from one revolving pulley to another because of friction between the pulley and the belt. Several types of belts are in



STITCHED CANVAS BELT
A.

SOLID WOVEN CANVAS BELT
B.

FIG. 35. CANVAS BELTS.

common use, the type selected being determined by the conditions under which the belt is used.

CANVAS BELTS

Canvas belts are used where materials coming in contact with them would deteriorate and ruin a belt made of leather or rubber. Canvas belts are usually made of cotton. The two general types are (a) stitched, shown in Fig. 35A and (b) solid woven, Fig. 35B. These belts are usually given a dressing of linseed oil to protect them from deterioration which might be caused by heat, steam or acid fumes.

RUBBER BELTS

Rubber belts, Fig. 36, are constructed of a backbone of canvas duck. In the best grade belts, only 32 ounce duck and new rubber is used. When all moisture has been removed from the canvas, the rubber compound is forced into the plies under pressure and then vulcanized. The working tension of a belt is largely sustained by

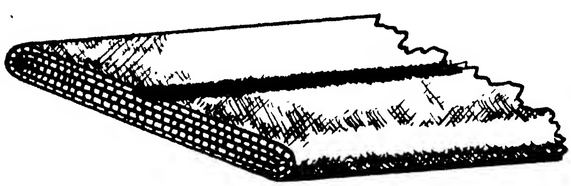
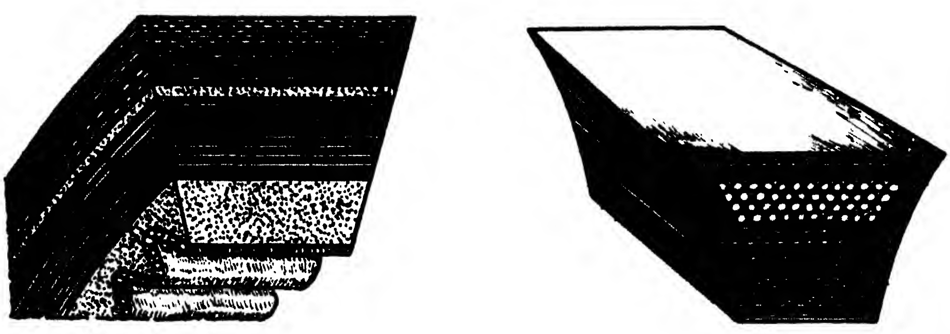


FIG. 36. RUBBER BELT.



COG V-BELT
A.

CONCAVE V-BELT
B.

FIG. 37. V-BELTS.

the canvas, the rubber making it more compact and creating added resistance to friction, abrasion and extreme temperatures. Fig. 37 shows two of the better types of V-rubber belts. Each makes a special provision for the bending of the belt around a sheave. The concave sides of the belt shown in Fig. 37A tend to straighten out as the belt curves around the sheave, making firm contact with the sheave groove. The cogged surface of the belt in Fig. 37B is not for the transmission of power but provides flexibility and prevents buckling when the belt is flexed around the pulley. This causes it to hug to the pulley arc and thus provides flat surfaces against the sides of the sheave groove.

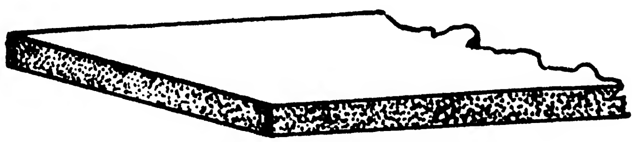


FIG. 38. LEATHER BELT.

LEATHER BELTS

The best leather belts, Fig. 38, are made from selected hides of mature steers killed in the fall of the year. The hides of old animals have lost some of their flexibility. The best wide belts are obtained only from the center back strip, which is about 30 inches wide and 50 inches long. As the distance from the spine increases, the stretching quality of the belt varies. For narrow belts, strips cut equally distant from either side of the backbone are spliced together for use, this making a belt which stretches evenly and runs straight over the pulleys.

Oak tanned leather is light in color and firm in texture. It is used for the general run of work. This leather is "curried" after tanning, i.e., treated with oil and tallow, to make it more flexible and to prevent cracking.

Single belts consist of one thickness of leather; double belting is composed of two thicknesses, the strips being cemented together. Heavier belts, made for special purposes, can be used only over extra large pulleys.

When a leather belt is spliced by using a cemented lap joint, the belt should run in such a direction that the thin edge of the splice on the inside of the belt is the first part to run over the pulley. (Fig. 39). Leather

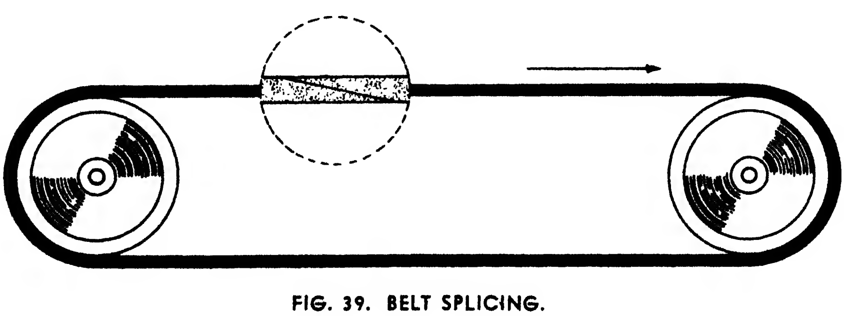


FIG. 39. BELT SPLICING.

belts give longer service if the hair, or grain side is placed next to the pulley.

BELT JOINTS

Belt lacing is an art learned by much experience. Fig. 40A shows the method for correctly lacing a belt. Care should be taken to keep the belt

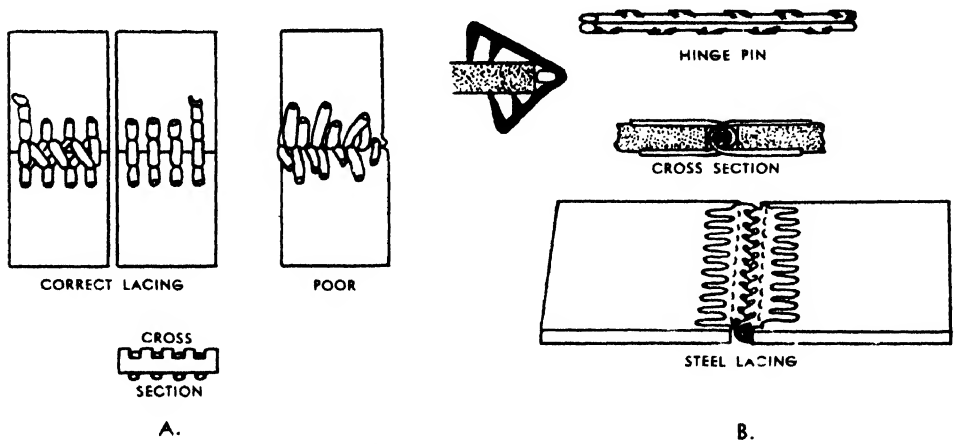


FIG. 40. BELT LACING.

ends exactly in line, lacing both sides with equal tension. The lacing should not be crossed on the hair (pulley) side.

STEEL LACING

Modern belt joints are made with steel lacing. This is easily and quickly installed and provides exceptional strength with long service for many types of belts. Fig. 40B shows a steel belt lacing.

BELT CARE

Belts should be kept reasonably clean and free from dust, dirt and grease. Belt dressing properly used will prevent slippage and keep the belt from becoming hard and dry.

BELT DRESSINGS

Suitable dressing materials for various types of belts are as follows:

Leather — Beef tallow, 2 lbs.; cod liver oil, 1 lb. Melt tallow, allow to cool slightly, then stir in oil until the mixture is cold. Apply in amounts that the belt will absorb. Never use rosin to prevent belt slippage because it soon hardens or glazes over, causing more slippage than before.

Rubber — A few drops of castor oil used with reason will serve as a dressing for rubber belts. *Never use animal oil or grease.*

Canvas — Use light applications of castor oil or linseed oil.

ARC OF CONTACT

The arc of contact is that portion of the pulley circle which the belt touches. When a large and a small pulley are joined by a belt, the arc of contact on the large pulley is greater than that of the small pulley. (See Fig. 41A.) Therefore the clinging effect will be less on small pulleys than

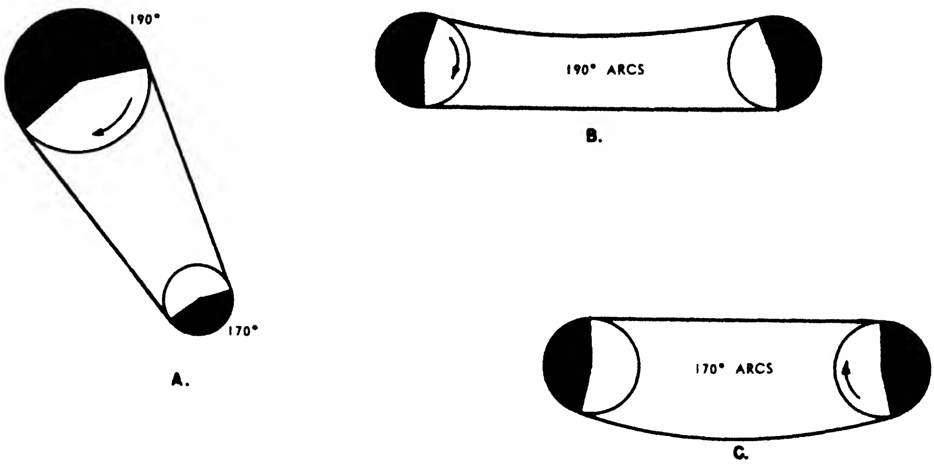


FIG. 41. ARC OF CONTACT.

on large pulleys. The arc of contact can be increased by having the slack side above (Fig. 41B) rather than below (Fig. 41C).

SIMPLE AND COMPOUND BELTING

Transmission of power from an extremely large pulley to an extremely small pulley is not recommended because of its effect on the length of arc contact. The intermediate jack shaft arrangement shown in Fig. 42 is a

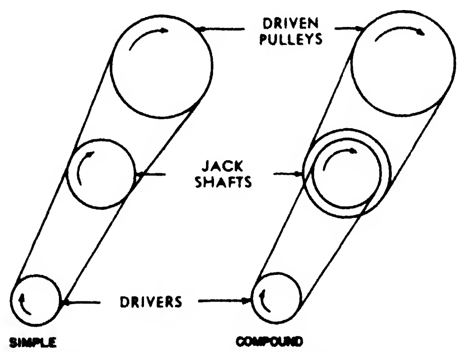


FIG. 42. SIMPLE AND COMPOUND BELTING.

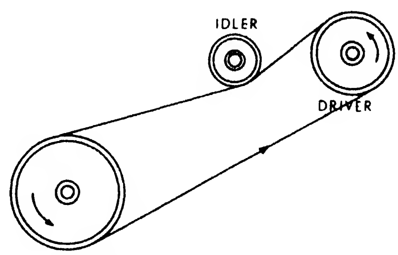


FIG. 43. IDLER PULLEY.

satisfactory way to forward power from a driver to a driven shaft. Arrangement (a) is known as simple belting because it has no effect on the speed of the driven pulley. Arrangement (b) is known as compound belting, the compound jack shaft (two wheels on the same axle — a wheel and axle) does change the speed of the driven pulley.

IDLERS

An idler pulley, Fig. 43, is used to keep the tension of the belt constant. It should be about one-fourth the distance from the driver on the slack side of the belt.

BELT SHIFTERS

The forks of a belt shifter should have a curved face or rollers to prevent wearing the edge of the belt and damaging the joint.

BELT TENSION

The recommended belt tension for a single leather belt is 60 lbs. per inch of width; 100 lbs. per inch for a double belt. A 4-ply canvas belt is equivalent to a single leather belt and a 6-ply canvas belt is equal to a double leather belt.

New Words:

DUCK.—A strong cotton material.
FLEXED.—The process of being bent.
JACK SHAFT.—An intermediate shaft.
MODIFIED.—Changed in form.
OAK TANNED.—Leather which has been tanned by being suspended in a tank containing a solution of weak tannic acid made from oak bark, etc.
SEMI-STEEL.—An iron product made by melting together pig iron and scrap steel.
SLACK.—That part of a stretched belt which is not taut (tight).

EXERCISES in BELTING

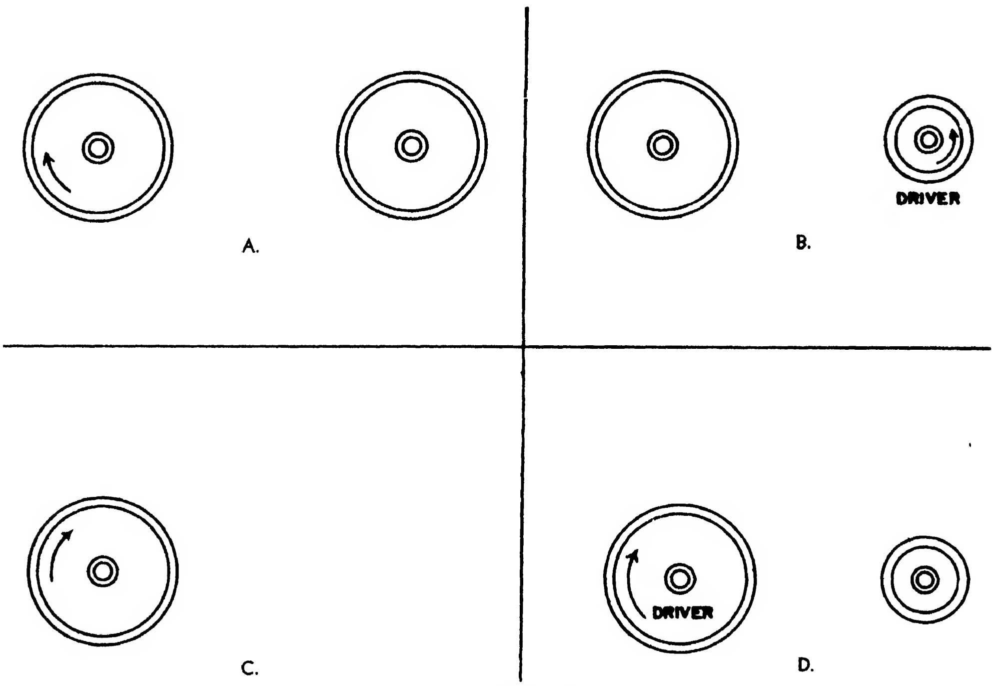


FIG. 44. BELTING PROBLEMS.

1. Complete the diagrams in Fig. 44 showing how a belt can be used in a pulley system to *a) Change direction of rotation b) Reduce speed c) Retain same speed d) Increase speed.*

2. (Select the proper word) The speed of a pulley is (directly, inversely) ....proportional to its diameter. This means that ....

3. A pulley is said to be "crowned" when ....

4. (Select correct answer) A (wood, steel, cast iron) .... pulley can be operated at the greatest r.p.m.

5. What metal is preferred for the manufacture of V-belt pulleys? .... Why? ....

6. Name three materials which are used for the manufacture of belts. a) .... b) .... c) ....

7. What kind of leather is preferred for belt manufacture? ....

8. How and why is a leather belt "curried"? ....

9. (Select answer) When a leather belt is spliced the (thick, thin) .... edge should be the first to pass over the pulley.

10. The (hair, flesh) .... side of the leather should be run next to the pulley in order to ....

11 Three common methods of joining leather belts are 1) .... 2) .... 3) ....

12 Upon what kind of belts can castor oil be used as a dressing? ....

13. What is meant by "arc of contact"? ....

14. Make a diagram showing when the arc of contact is *more than 180°; less than 180°.*

15. When is belting said to be "compounded"? ....

16. Why should rosin not be used for a belt dressing? ....

17. What is an "idler" in a belt system? ....

....

18. What belt tension is recommended for general use? ....

....

PULLEY SPEEDS

Purpose:

To learn to calculate pulley speeds and pulley diameters.

Introduction:

The calculation of pulley speeds and pulley diameters is simplified when it is remembered that their speed is inversely proportional to their diameters, i.e. the larger the diameter of the pulley, the slower its speed and the smaller the diameter of the pulley, the more rapid its speed.

If D = Driver diameter
d = diameter of the driven pulley
R = driver speed
r = speed of driven pulley

The statement of this inverse proportion is —

$$\frac{D}{d} = \frac{r}{R}$$

This statement can be rearranged to find any one of the four quantities.

If it is desired to find the diameter of the driver —

$$D = \frac{dr}{R}$$

Example:

The speed of the driving pulley is 250 r.p.m. Speed of the driven pulley is 400 r.p.m. Diameter of driven pulley is 6 inches. Find the diameter of the driving pulley.

$$\begin{aligned} D &= \frac{dr}{R} \\ &= \frac{6 \times 400}{250} \\ &= 9.6 \text{ inches} \end{aligned}$$

The same principle applies to a pulley train, however here the product of the diameters is used, thus —

$$\frac{\text{Speed of the first driver}}{\text{Speed of the last driven}} = \frac{\text{Product of diameters of driven pulleys}}{\text{Product of diameters of driving pulleys}}$$

Solve the problems in the following exercise. Arrange your work in a neat and systematic order.

1. The pulley sheave on the end of the crankshaft of an automobile motor, Fig. 45, revolves at 1000 r.p.m. when the car is traveling at 20 miles per hour (m.p.h.)
   a) Calculate the speed (r.p.m.) of the fan.

   b) Calculate the speed (r.p.m.) of the generator.

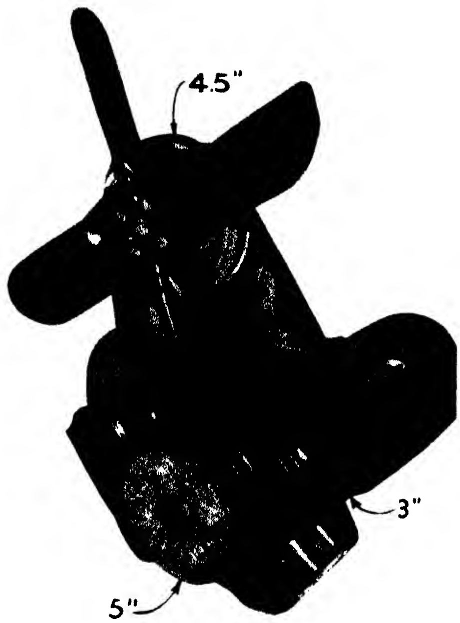


FIG. 45. AUTO FAN.

2. Find the peripheral speed (rim speed) of the grinding wheel, Fig. 46, in (a) feet per minute (f.p.m.) and (b) in miles per hour (m.p.h.) The diameter of the motor pulley (D) is 2.5″ while that of the grinder pulley (d) is 3″. The motor speed is 1750 r.p.m. and the diameter of the carborundum wheel is 6″.

a) *b)* *c)* *d)*

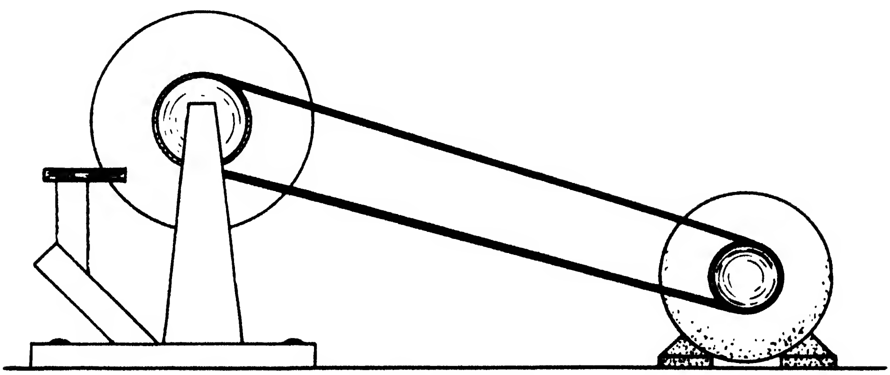


FIG. 46. GRINDER.

3. The motor and belt drive mechanism of a well known machine lathe is shown in Fig. 47A. The four pulleys on the upper and lower cones are 3″, 4.5″, and 7″ in diameter. The motor pulley is 2″ in diameter and the counter shaft driving pulley is 12″ in diameter. The motor operates at 1800 r.p.m. Calculate the four speeds at which the work can be turned when the lathe is on direct drive.

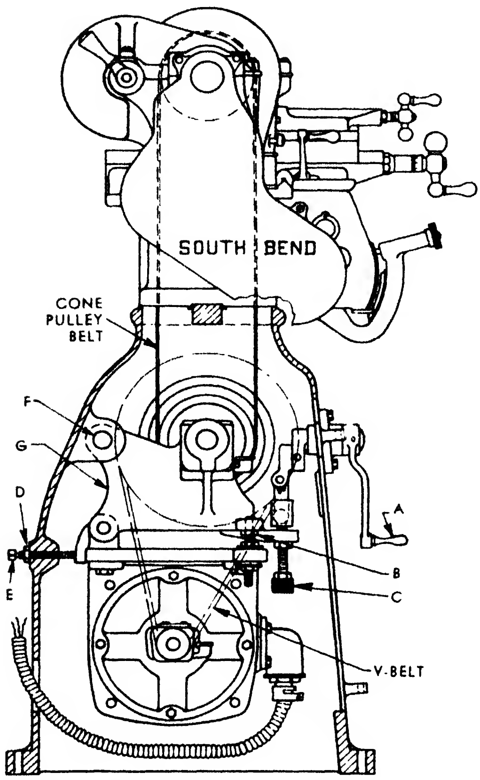


FIG. 47A. SOUTH BEND LATHE DRIVE.
(Courtesy, South Bend Lathe Works.)

Formula

$$\frac{\text{Driver speed}}{\text{Driven speed}} = \frac{\text{Prod. of driven diam's.}}{\text{Prod. of driver diam's.}}$$

a)

b)

c)

d)

4. The pulley sheaves on the cone pulleys of the drill press Fig. 48 are 1″, $1\frac{3}{8}$″, $2\frac{3}{8}$″, $2\frac{7}{8}$″ in diameter. A $\frac{3}{8}$″ highspeed drill, drilling cast iron, should operate at 610 r.p.m. What combination of pulleys should be used to obtain this operating speed? Show your calculations.

5. A $\frac{3}{8}$″ high speed drill is used for drilling brass. The $2\frac{3}{8}$″ pulley on the motor cone, Fig. 48 is used. *a)* Find the r.p.m. of the drill.

   b) Find the peripheral speed of the drill in feet per minute (f.p.m.).

6. What is the speed of a belt (f.p.m.) running over a 36″ pulley turning 350 r.p.m.?

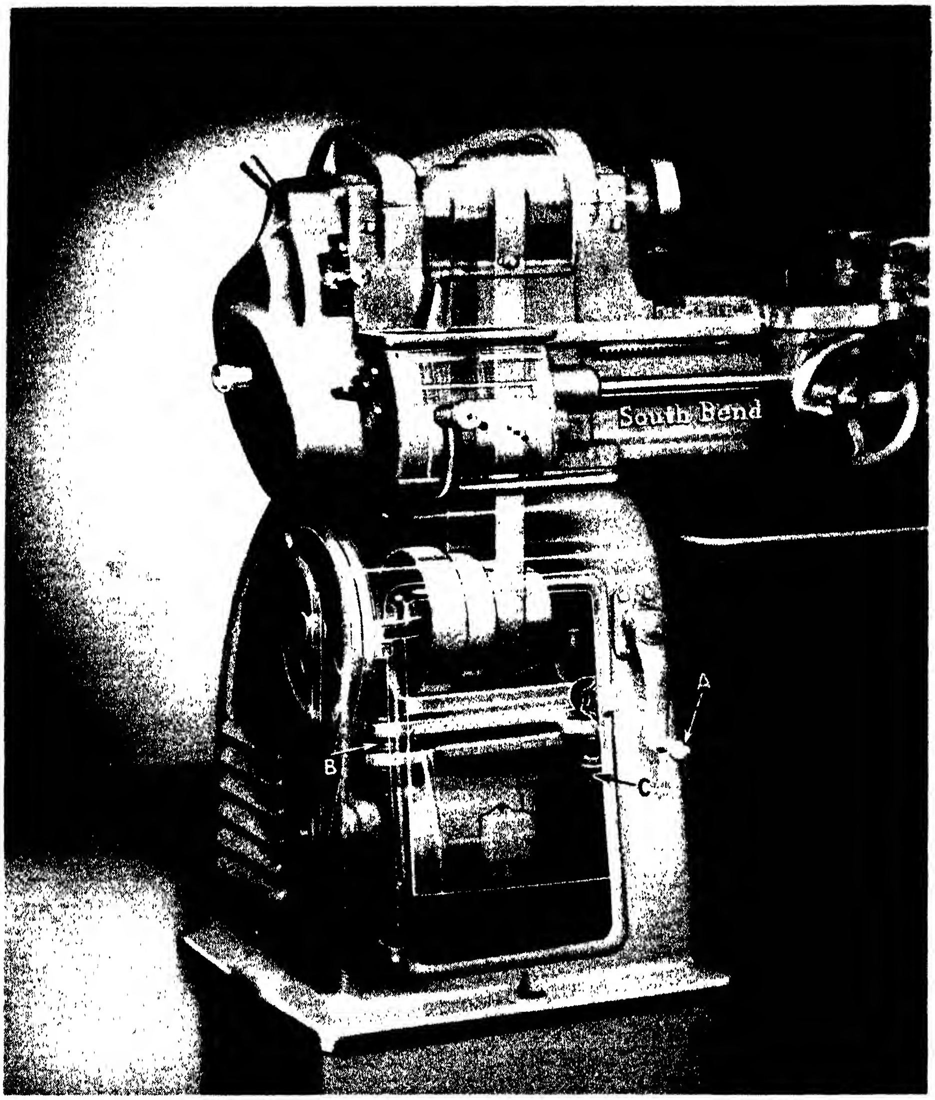


FIG. 47B. SOUTH BEND LATHE DRIVE. (Courtesy, South Bend Lathe Works.)

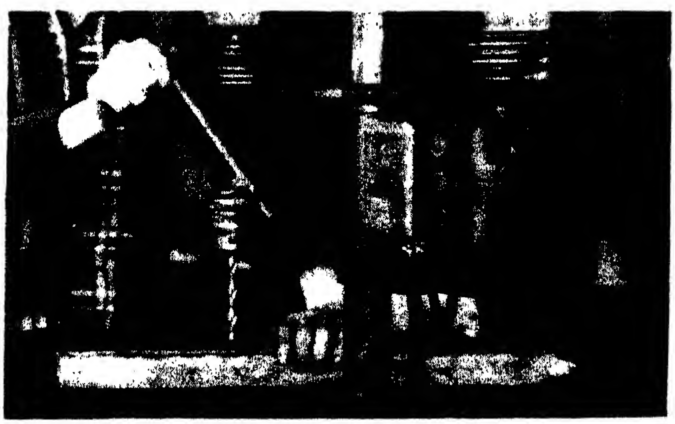


FIG. 48. A SMALL DRILL PRESS.

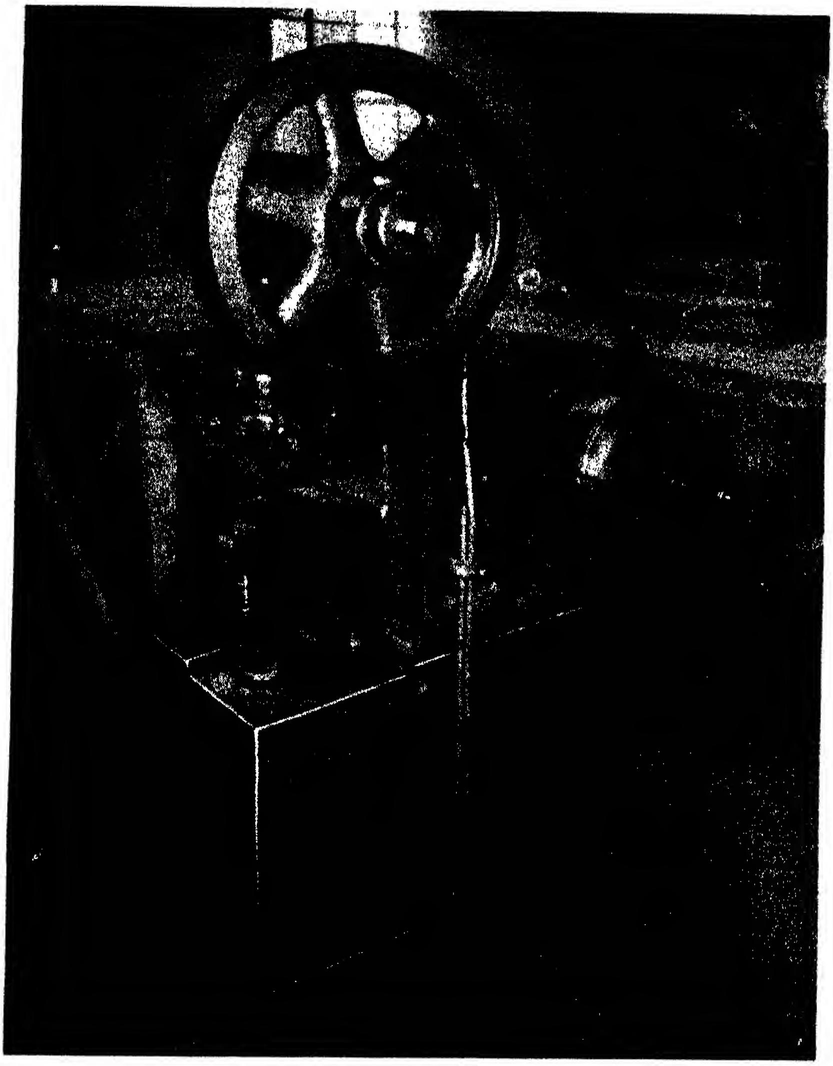


FIG. 49. PUNCH PRESS.

7. The belt wheel of a punch press, Fig. 49, turns 250 r.p.m. when driven by a motor running at 1800 r.p.m. The belt pulley on the motor is 2.5″ in diameter. Find the diameter of the belt wheel on the punch press.

MACHINES

A machine is a device for transferring or transforming energy. It may be used to gain mechanical advantage, to increase or decrease speed or to change the direction in which the force is to act. There are six simple machines, namely: (1) the lever, (2) the wheel and axle, (3) the

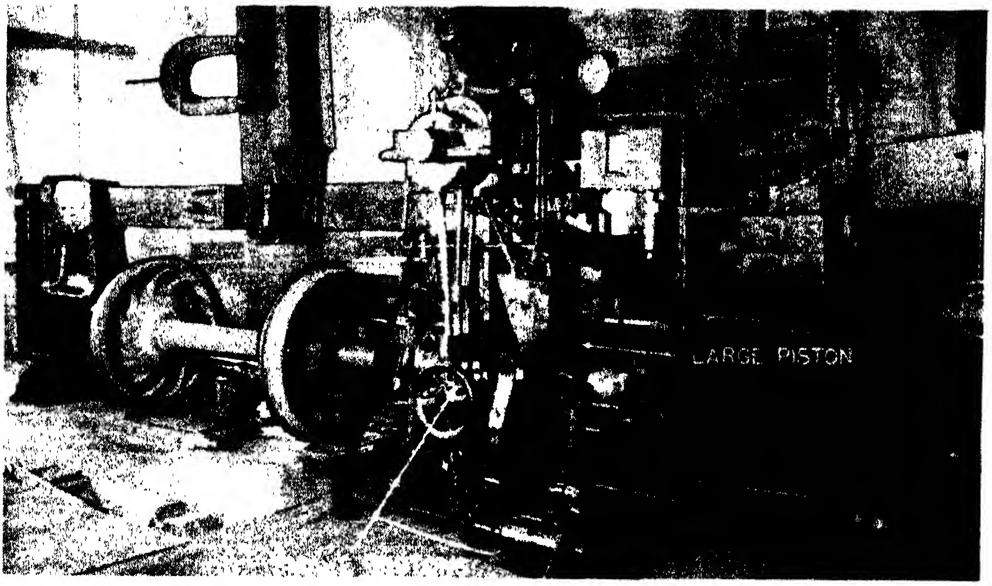


FIG. 50. A HYDRAULIC PRESS USED TO FORCE FREIGHT CAR WHEELS ON THEIR AXLE. (Courtesy, American Car & Foundry Co.)

pulley, 4) the inclined plane, 5) the screw, and 6) the wedge. The first three named are, in reality, levers while the last three are inclined planes. The hydraulic press, Fig. 50 is the seventh type of machine which is frequently used to gain great mechanical advantage. All compound machines are combinations of two or more of the seven machines just mentioned.

In dealing with machines the following words are frequently used. The meaning of these terms should be thoroughly understood.

Input — Energy a machine receives from an outside source.

Output — Energy that a machine delivers. Output is always less than the input because of friction.

Energy — The ability to do work.

Work — The overcoming of resistance. Work is the product of a *force* and the *distance* through which it acts.

$$W = Fd$$

Efficiency — Ratio of the output of a machine to its input. Efficiency is always less than 100%.

$$E = \frac{\text{output}}{\text{input}}$$

Mechanical advantage (M.A.) — The ratio of the resistance to the effort; a number showing how many times the resistance is greater than the effort used to overcome it.

$$\text{M.A.} = \frac{R}{E}$$

Velocity ratio — The ratio of the distance the effort moves to the distance the resistance moves in a given time.

Law of machines (frictionless) — The product of the effort and the distance the effort moves equals the product of the resistance and the distance the resistance moves.

Machine Law —

$$E \times D = R \times D$$

Practical Definition —

Machine Law —

$$E \times D \times \text{Efficiency}^{*} = R \times D$$

* When using this formula, efficiency should be expressed as a decimal.

FRICTION

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 58-62.
Dull: *Modern Physics*, pages 156-160.
Fletcher: *Unified Physics*, pages 108-110.
Holley and Lohr: *Mastery Units in Physics*, pages 210-214.
Kuns: *Automotive Essentials*, pages 359-378; 126-145; 317-329.
Leigh and Mangold: *Practical Mechanics and Strength of Materials*, pages 139-156.
Machinery's Handbook, pages 505-546 (11th edition).
Millikan: *New Elementary Physics*, pages 178-181.
Smith: *Mechanics*, pages 105-112.
South Bend, *How to Run a Lathe*, page 98.
War Department —
TM-10-540 *Automotive Lubrication*, pages 3-4.
TM-10-565 *Automotive Brakes*, pages 7-10.

SLIDING FRICTION

Friction is a force which acts only when one body is being moved in contact with another, acting then to prevent such motion. Solid or sliding friction may be caused by the interlocking of the irregularities of one surface with those of another, Fig. 51. For one object to move over another it must either be lifted so that these irregularities unlock, or the surface must be made smooth by shearing off the raised portion. Both of these operations require force. As long as the pressure per square inch (normal pressure) on the bearing surface does not exceed the elastic limit of the material, *friction is not dependent upon the area of contact between the two surfaces. Friction is dependent* upon the materials rubbing together and the normal pressure.

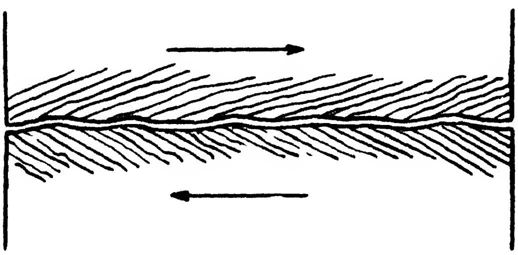


FIG. 51. FRICTION BETWEEN SOLIDS.

The relation between the force of friction (F) and the normal pressure (N) is called the "coefficient of friction" and is usually represented by the greek letter "Mu" (μ)

$$\mu = \frac{F}{N}$$

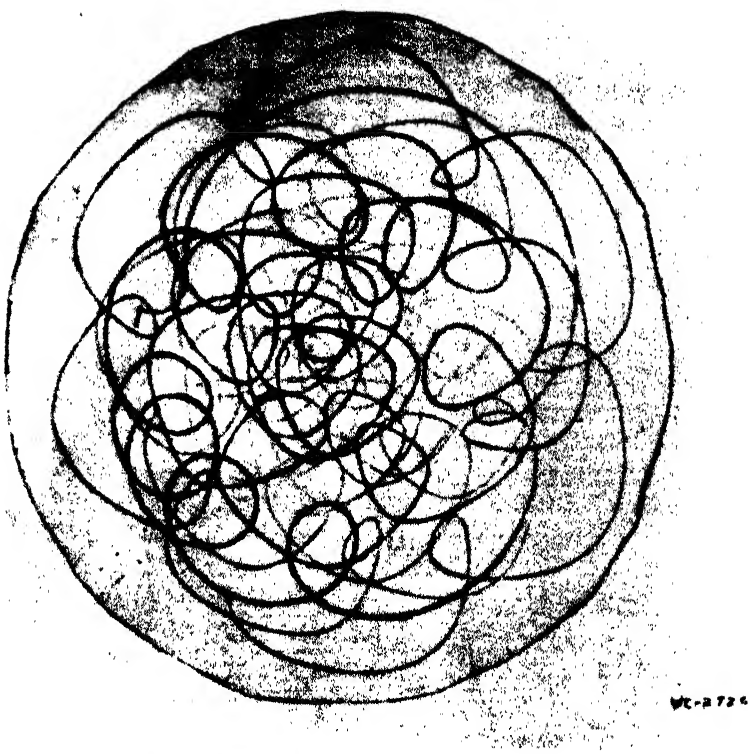


FIG. 52A. MULTIMOTION PATH OF ABRASIVE STONES. (Courtesy, Chrysler Corporation.)

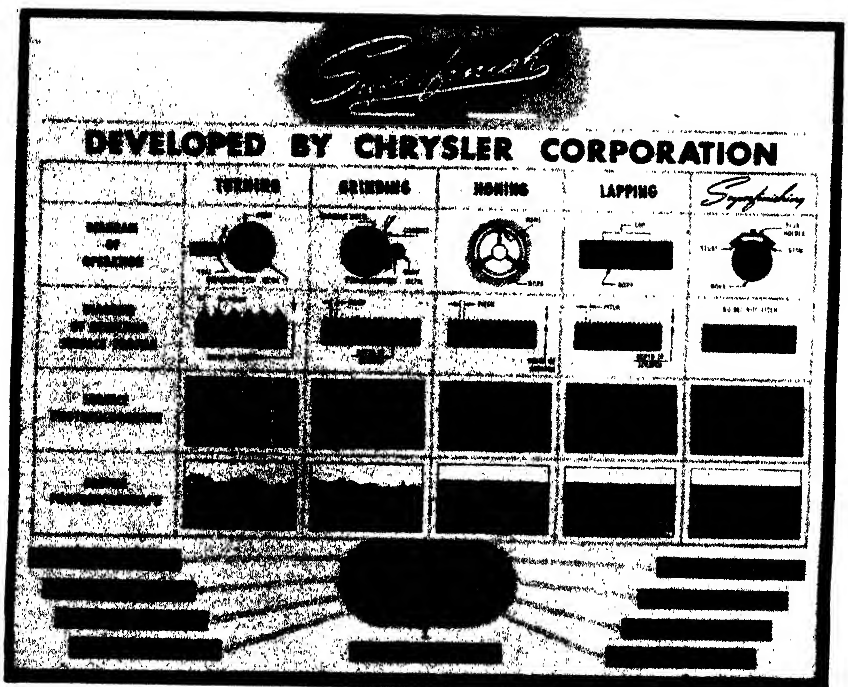
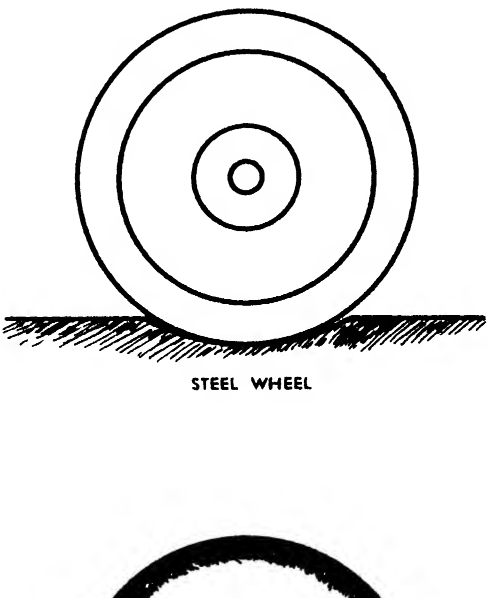
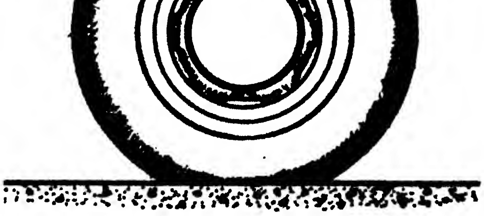


FIG. 52B. SUPERFINISH. (Courtesy, Chrysler Corporation.)

Friction may also be increased by making a surface extremely smooth. This is now being accomplished by "superfinishing" metal parts. Superfinishing is an operation which removes the "rough-teeth" on metals produced by turning or grinding. It is accomplished by a *multimotion* (See Fig. 52A) which provides an endless variety of patterns for the path of the lubricated abrasive stones, so that the surplus material is removed without depositing abrasive grit. Thus a surface condition of optical flatness is obtained. Rough, fragmented material left on the surface by previous grinding operations is removed in chip form by superfinishing. The chips are cleanly cut, but of extremely small dimensions. Fig. 52B shows the result of "superfinishing." Superfinishing machines are used to smooth clutch plates and brake drums, so as to increase friction in these parts. The explanation of this increased friction is that the total contacting area is greatly increased due to the extreme smoothness. This brings the molecules of the contacting surfaces into intimate contact with each other, thus increasing the adhesion between the two surfaces. Friction is usually greater between surfaces made of the same materials.



STEEL WHEEL



PNEUMATIC TIRE

FIG. 53. ROLLING FRICTION.

KINDS OF FRICTION

Greater force is required to start a body moving than to continue it in uniform motion. Hence we say the "static" friction is greater than "kinetic" friction.

Since all materials are elastic to some degree, a wheel flattens slightly under weight and the surface on which it rests is slightly depressed (See Fig. 53). The net result of this is that the wheel is always rolling uphill, thus consuming energy. The coefficient of rolling friction is found by the formula

$$\mu = \frac{Rr}{W}$$

Where R = resistance to rolling
r = radius of the wheel
W = total weight on the wheel

Friction also is present in fluids, both liquid and gas, the resistance to motion being produced when the molecules slide over each other. Friction causes wasted energy which shows up in the form of heat, this heat being greatest with solid friction, less with rolling friction, and the least in the case of fluid friction.

LAWS OF FRICTION

Definite laws of friction have been difficult to determine. However, the following laws have been established.

1. Friction is directly proportional to the normal pressure between two surfaces at low pressures. Friction increases as the pressures rise to a high value, and when pressure is abnormally high, friction increases at a rapid rate until "seizing" occurs.
2. Friction is not dependent upon the amount of area in contact at moderate pressure. For high pressures, the law follows that given in (1).
3. Friction is not dependent upon speed at low velocities. At increased speed friction decreases (in solids).
4. Fluid friction is less than solid friction but increases as the square of the velocity.
5. For well lubricated surfaces, friction is almost independent of the pressure per square inch.
6. For well lubricated surfaces, friction is almost independent of the nature of materials in contact. With less ample lubrication, friction becomes more dependent on the materials composing the surfaces in contact.

COEFFICIENTS OF FRICTION

Sliding Friction		Leather on hard wood	.33
Bronze on bronze	.20	Leather on cast iron	.56
Bronze on cast iron	.21	*Rolling Friction*	
Cast iron on cast iron	.15	Wood on wood	.005
Cast iron on hard wood	.49	Iron on iron	.002 to .005
Hard wood on hard wood	.48	Iron on wood	.018

TABLE XIX

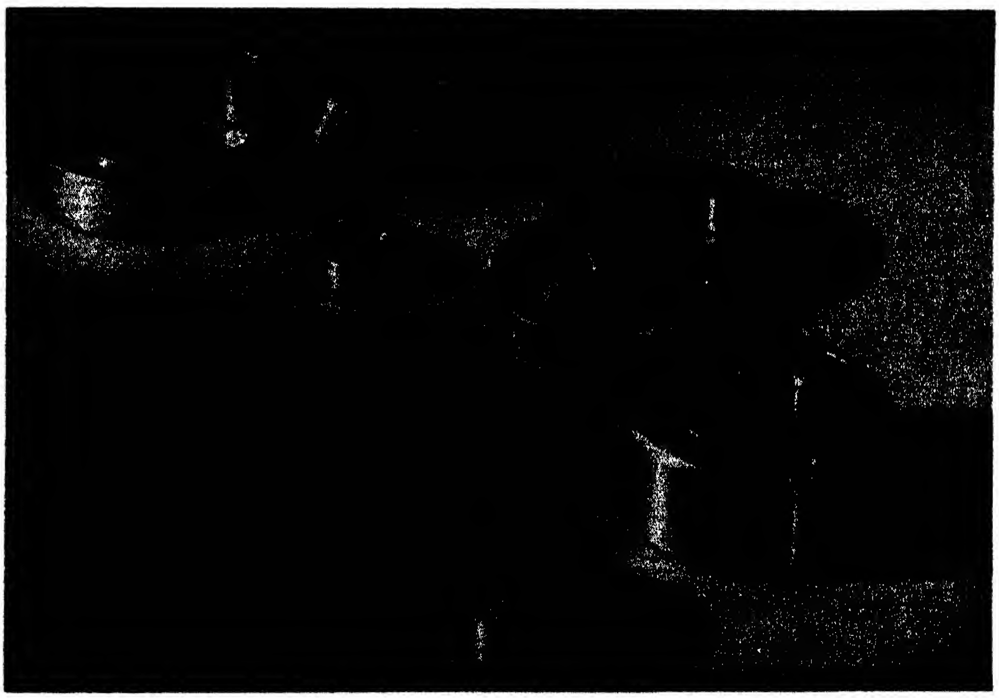


FIG. 54A. BALL BEARINGS. (Courtesy, New Departure Ball Bearings.)

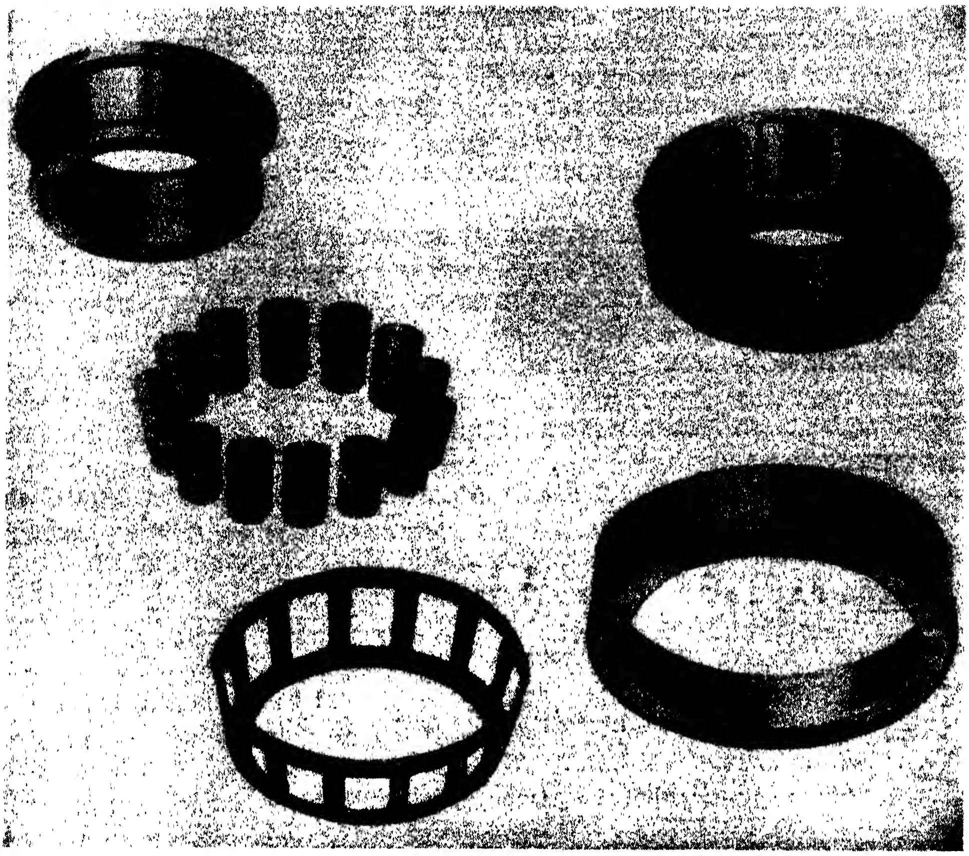


FIG. 54B. (Courtesy, Timken Roller Bearing Co.

CHANGING FRICTION

There are many examples of both useful and of undesirable friction. When in motion an automobile must have friction in the clutch, also between the tire and the road; and friction in the brakes in order to stop. Locomotives use sand to increase the friction between the driving wheels and the track. In many moving parts, friction is undesirable since it causes undue wear and loss of energy which reduce the efficiency of the machine. Many methods are employed to reduce friction. Lubrication is used to reduce friction in bearings having "all over" contact such as connecting rod bearings, (friction bearings) and in ball or roller bearings (antifriction bearings). Since antifriction bearings have point (ball) or line (roller) contact, they require a minimum of lubrication as compared with the surface of a plain bearing. Fig. 54A shows typical examples of ball bearings. Fig. 54B shows the four basic parts of any antifriction bearing, namely a) the outer race (fixed to the housing); b) inner race (fixed to the shaft); c) balls or rollers; d) retainers, commonly called "cages."

There are four basic types of antifriction bearings:

1. The Single Row Deep Groove Ball Bearing sometimes referred to as the Conrad type. (See Fig. 54C). This bearing is designed with deep un-

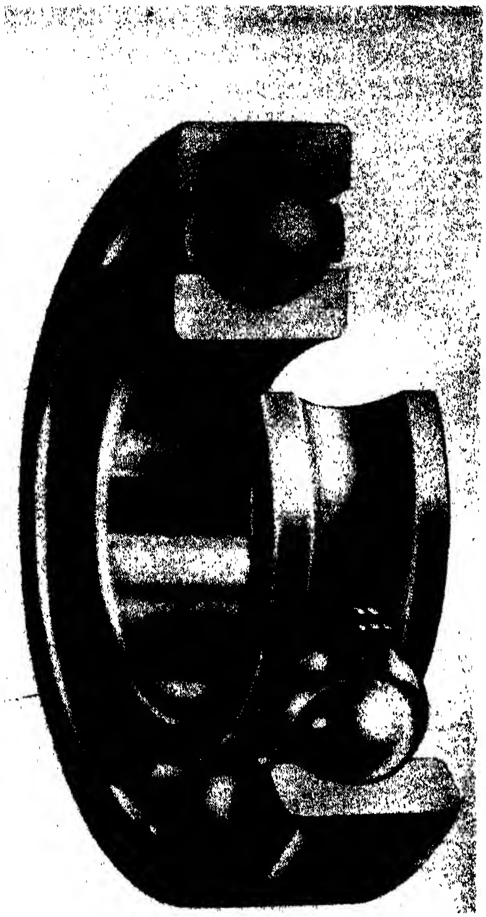


FIG. 54C. (Courtesy S. K. F. Industries, Inc.)

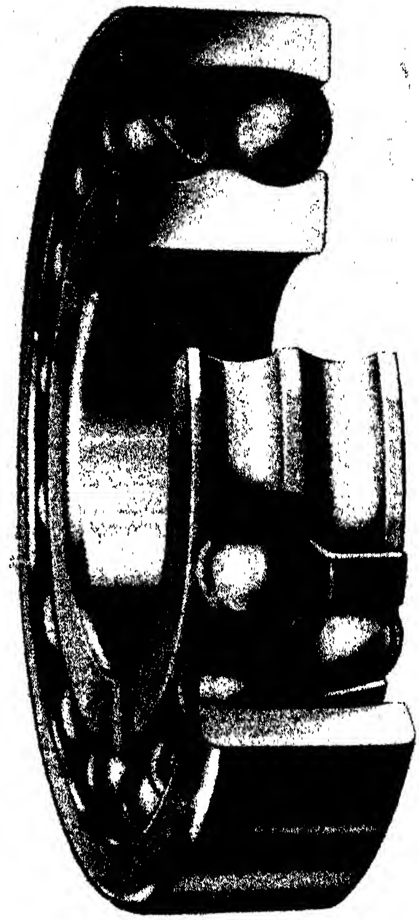


FIG. 54D. (Courtesy, S. K. F. Industries, Inc.)

interrupted symmetrical races, the curvature of the grooves conforming closely to the balls for large contact areas. This permits the bearing to carry high radial loads (up and down), and some thrust loads (sideways). Each ball has a "point" contact. This bearing is usually selected where high speeds and light loads predominate such as in high speed grinders, woodworking machinery and in automotive applications where precision under high speeds is needed.

2. The Self-Aligning Ball Bearing is self-contained, and has two rows of balls, each ball having a "point" contact. See Fig. 54D. The inner surface of the outer race is spherical. Therefore this bearing embodies the self-aligning feature which enables it to compensate satisfactorily for the unavoidable conditions of misalignment caused by frame distortion or shaft deflection without impairing its full load carrying capacity. Where the deep groove bearing operates in a "fixed" position, the self-aligning bearing can easily be displaced. It is used extensively for slower

speeds and greater loads than carried by the deep-groove ball bearing, such as in farm and road machinery, and electric motors.

3. The Cylindrical Roller Bearing has a single row of cylindrical rollers guided by flanges on one or both races. (See Fig. 55A) Because of the

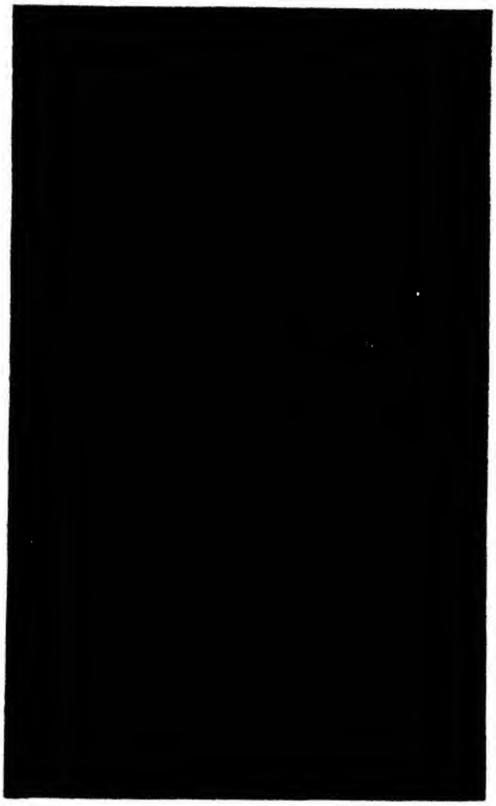


FIG. 55A. (Courtesy, Hyatt Roller Bearing Division General Motors Corporation.

FIG. 55B. (Courtesy, S. K. F. Industries, Inc.)

"line" contact surfaces between rollers and races, this bearing is used to take loads heavier than self-aligning ball bearings at deep-groove ball bearing speeds. It is dimensionally interchangeable with corresponding single row ball bearings. These bearings are used for machine tool spindles, aircraft crankshaft locations, and Patrol Torpedo boat drives where heavy radial loads and high speeds are governing factors.

4. The Spherical Roller Bearing, Fig. 55B is a "big brother" to the Self-Aligning Ball Bearing. The principal difference is the "line" contact of each roller instead of the "point" contact of a ball. The longer the line, other dimensions in proportion, the greater the load it can carry. This bearing also has the inherent properties of alignment, and barrel-shaped rollers are designed to remain in permanent contact with the center flange, assuring positive roller guidance. This bearing withstands heavier loads and lower speeds than the three other types and is used in back-up rolls in steel mill stands, propeller thrust locations on marine applications and in quarry machinery where brute loads at low speeds predominate.

An easy way to remember the types of antifriction bearings is to

imagine Type 1 as a skinny, long-legged guy who can run like the wind but who isn't strong enough to carry much load. Type 2 hasn't such long legs, but has fairly strong shoulders. Type 3 is a bit taller with a pair of broad shoulders, while Type 4 is a short, broadshouldered guy with a bellows for a chest and hands like hams.

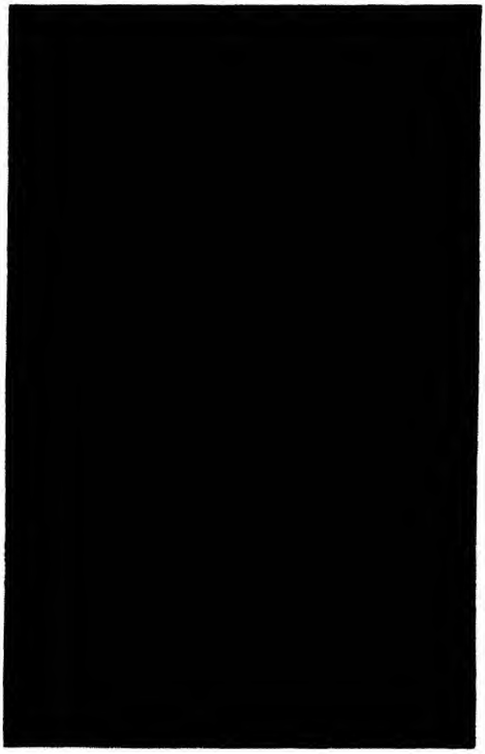


FIG. 55C. (Courtesy, Timken Roller Bearing Co.)

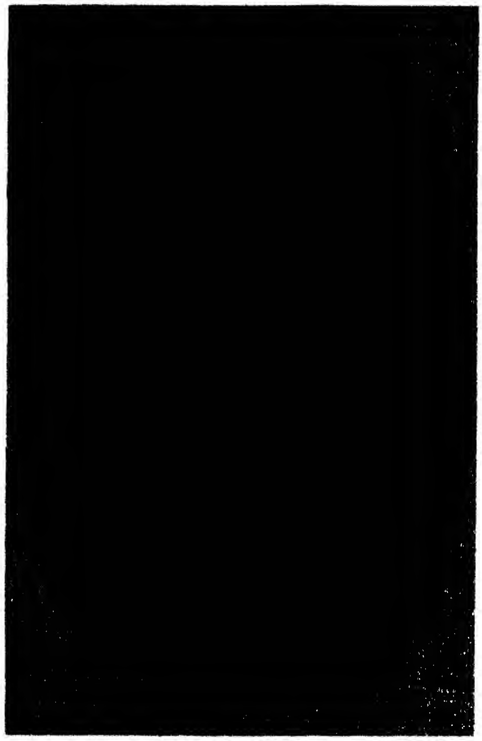


FIG. 55D.
(Courtesy, Timken Roller Bearing Co.)

Fig. 55C shows a tapered roller bearing used in a steering gear. This differs from the conventional tapered roller bearing in that the cone is usually formed on the worm at the end of the steering column so that only a cup and roller asembly is needed.

Fig. 55D shows a thrust bearing. It is made in many sizes capable of withstanding loads from 1000 pounds to 200,000 pounds.

Fig 55E shows a four row bearing, having a maximum capacity when used in limited space.

Fig. 55F shows a helically wound, roller type bearing. The rollers are wound with both right-hand and left-hand turns and are assembled alternately in the bearing. This arrangement has the effect of sweeping the lubricant back and forth across the bearing surface, cleaning it of all dirt, grit and foreign matter, thus insuring continuous and complete lubrication of all parts of the bearing.

FRICTION BEARINGS

There are many alloys known as "babbitt" metal. They are so called from the name of the inventor, Isaac Babbitt. The original babbitt alloy

FIG. 55E. (Courtesy, Timken Roller Bearing Co.)

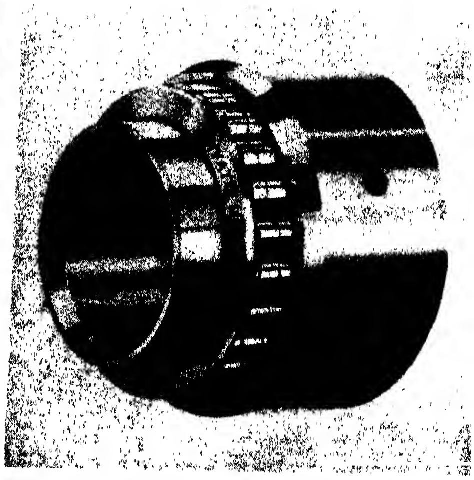


FIG. 55F (Courtesy, Hyatt Bearing Division, General Motors Corporation.)

was 89.3% tin (Sn); 3.6% copper (Cu); and 7.1% antimony (Sb). This metal has great antifrictional properties, the wear being most on the small particles of hard antimony. These particles show light in color in the photomicrograph, Fig. 56. The tin makes babbitt an expensive metal

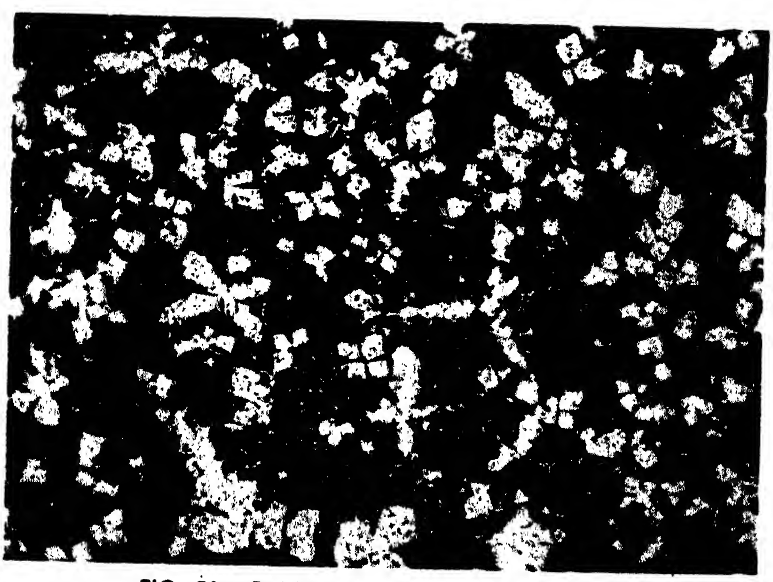


FIG. 56. BABBITT METAL (Magnification 200X).

and for this reason other metals such as copper and lead have been substituted. However, the alloy is still being marketed as "babbitt" metal.

There are many bronze alloys, S.A.E. No. 64, commonly known as phosphor bronze, being a typical example. It is composed of 78.5% to 81.5% Cu (copper); 9% to 11% Sn (tin); and 9% to 11% Pb (lead). It has good antifrictional qualities and stands up well under heavy loads.

Recently a new type bearing material has been perfected for use in high speed and heavy duty engines. This is an alloy made of cadmium, silver and copper, which gives about 50% greater mileage than babbitt. It has a low coefficient of friction, resulting in cooler running bearings.

Porous bronze bearings, which are to some extent self lubricating, are made by pressing the powdered metals and graphite together. The pressed metal is then subjected to a high temperature, converting it into an alloy resembling cast bronze. Being much more porous than cast metal due to the method of manufacture, the pores serve as reservoirs for oil, making the bearing useful in places where oiling is undesirable or where the bearing is difficult to reach for oiling purposes.

SILVER SURFACED BEARINGS

War plane engines achieve new records in withstanding the terrific strains and stresses experienced under the toughest conditions, due to a new process which has been developed for coating a base metal backing with the more expensive silver metal. This makes possible an immensely better engine bearing at an economical production cost.

New Words:

JOURNAL.—That part of a shaft which is supported by and revolves within the bearing.

MULTIMOTION.—Motion occuring in many directions.

PHOTOMICROGRAPH.—A photograph made through a microscope.

SEIZING.—Taking hold of suddenly.

Additional New Words:

__________ ....

....

__________ ....

....

__________ ....

....

COEFFICIENT OF FRICTION

Purpose:

1. To compare starting friction (static friction) with sliding friction (kinetic friction).
2. To study some factors which affect friction.
3. To compute the coefficient of friction for several substances.

Tools and Materials:

Smooth oak board 4 ft. x 6 in. x 1 in., fixed pulley mounted on one end
Oak block, 2 in. x 8 in. x 6 in., smooth, with hook in one end
Ground steel plate, 3 ft. x 4 in. x $\frac{1}{2}$ in., fixed pulley mounted on one end
Steel block, 4 in. x 4 in. x 1 in. with hook in one end
Oak block, 2 in. x 6 in., brake lining fastened to one side
Small steel cylinder, 6 in. long — Block of weights
Weight hanger — Cord

Procedure:

a) Sliding friction

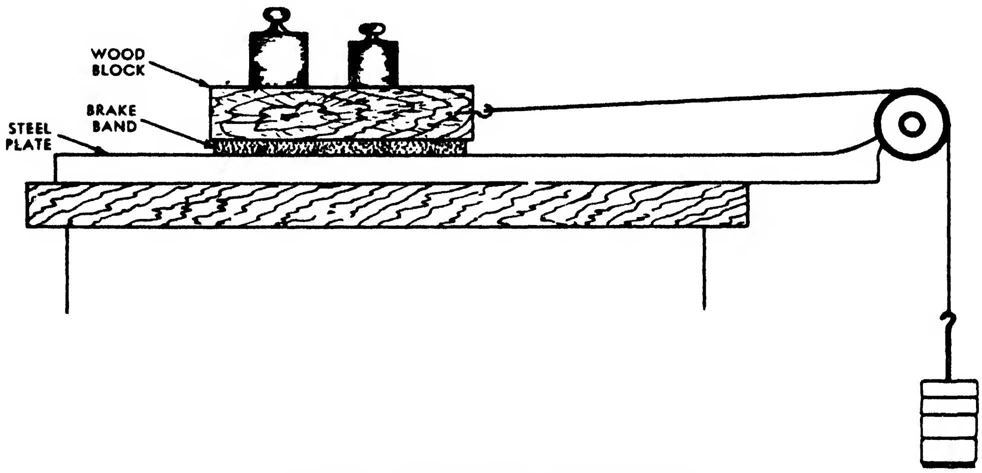


FIG. 57. COEFFICIENT OF FRICTION.

Arrange the friction board as shown in Fig. 57. Weigh the oak block. Fasten a weight hanger to the block with a strong cord, then place weights on the weight hanger until the block slides along the board at a uniform speed. It will be necessary to give the block a few light taps to start it in motion. Why? Repeat the test with the block turned on its edge; also repeat with 1000 g. weight placed on the block. Record all the information in Table XX and calculate the coefficient of friction (μ) for wood on wood.

	BLOCK		
	Large base	*On edge*	*Block + 1000 g.*
Total Load (N)			
Sliding force (F)			

Calculations

Coefficient of friction $\mu = \frac{F}{N}$

TABLE XX

Repeat the experiment, using the steel plate and steel block. Also use the wooden block having the brake band fastened to it, weighted with 1000 g. Record the information in Table XXI and calculate the coefficient of friction (μ).

	Steel block	*Brake bands*
Total Load (N)		
Sliding force (F)		

Calculations

Coefficient of friction $\mu = \frac{F}{N}$

TABLE XXI

b) Rolling friction

Place three small iron cylinders between the wooden block and the friction board and determine the force necessary to move the block uniformly along the board. Calculate the coefficient of friction.

Weight of block (W) .... Rolling force (R) ....

Radius of cylinders (r) ....

Calculations

Coefficient of rolling friction $\mu = \frac{Rr}{W}$

Questions and Problems:

1. The figures obtained by the preceding experiment show that the coefficient of friction (is, is not) .... dependent upon the load.
2. What is friction? ....

....
3. The diagram, Fig. 51, illustrates two surfaces rubbing together. What does it show one cause of friction to be? ....

....
4. What effect does an increase in speed have on the amount of friction between two solids? ....

....

Between a solid and a fluid? ....

Give examples to illustrate. ....

....

....

5. Coefficient of friction is the ratio of .... to ....
What is meant by the term "ratio "?..
....
Give an example of a ratio ....
6. What is meant by the term "coefficient"? ....
....
Give example ....
7. Give six examples of helpful friction. (a)..
(b) .... (c)..
(d)............................ (e)................................ (f)...........................
8. Upon what two factors does friction depend? ....
....
9. In what three ways can friction in a machine be lessened? ....
....
10. What is "Chrysler's — Superfinish" and how does it affect friction?
....
....
11. Friction causes work to be wasted, the energy of motion being changed into ....
12. Friction, sliding or rolling, is (directly, inversely) .... proportional to the pressing force.
13. Why is it more difficult to run a shop truck with small iron wheels over a rough floor than it is a truck with large wheels? ....
....
....
Make a diagram to illustrate your answer.
14. Why is rolling friction less than sliding friction? ....
....
15. Does sliding friction increase with pressure? ....
.... Does the coefficient of friction increase with pressure? ....

16. The starting force is greater than the sliding force because it is necessary to overcome the .... of the object.

17. A railroad locomotive weighs 100 tons. The coefficient of friction between the driving wheels and the track is .17. What is the maximum pull (traction) that the locomotive can exert before the wheels begin to slip? Show your work.

18. A turret lathe, too heavy to be lifted, is dragged 20 feet while being placed. It weighs 3000 pounds and requires a force of 500 pounds to slide it into place, what is the coefficient of friction?

SIMPLE MACHINES (Lever Group)

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 18-41; 63-65.
Dull: *Modern Physics*, pages 175-187.
Fletcher: *Unified Physics*, pages 143-156.
Holley and Lohr: *Mastery Units in Physics*, pages 217-220; 223-230; 233-240.
Kuns: *Automotive Essentials*, pages 362-363.
Millikan: *New Elementary Physics*, pages 149-165.
Smith: *Mechanics*, pages 114-122.
War Department —
TM-10-565 *Automotive Brakes*, pages 5-7.

All machines are combinations of two or more simple machine principles. As previously stated, simple machines are of two types, those which use the lever principle and those which are based upon the principle of the inclined plane.

It is believed that the lever was the first machine. Man, in his con-

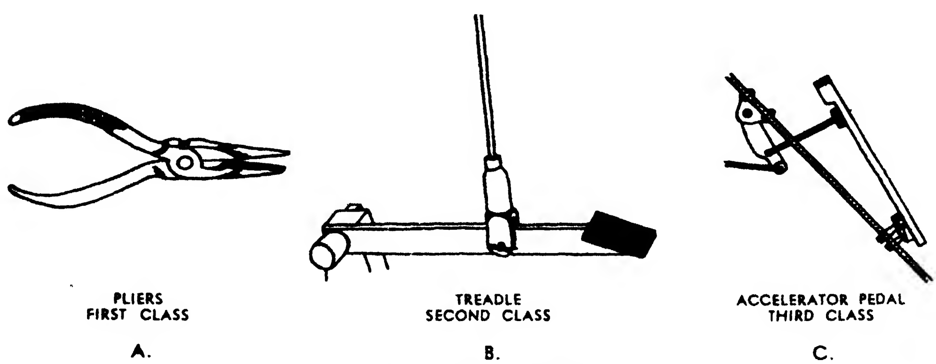


FIG. 58. LEVER EXAMPLES.

quest of nature, soon discovered that it was easier to move a heavy rock by prying under it with a long stick than by trying to lift or shove it. Practically every machine makes use of the lever principle in some part of its mechanism. Observation will reveal many examples of lever similar to those shown in Fig. 58.

The lever is a non-flexible bar, free to rotate upon a fixed axis called the fulcrum. The lever bar may be bent or straight, uniform or non-uniform, but it must have sufficient strength that the pressures applied will not strain it beyond its elastic limit. The fulcrum of a lever may be a triangular (△) or knife edged support, or it may be a spindle passing through the bar. The bar must be free to rotate upon the fulcrum with as little friction as possible.

For simplicity, levers are classified in three groups. First and second class levers are used to gain mechanical advantage, that is, to multiply the effort, while the third class of levers is used to increase speed. The first class lever, Fig. 59, has the fulcrum between the resistance (R) and

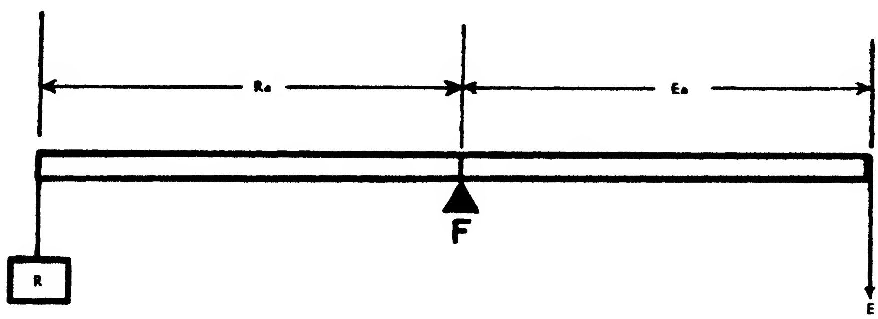


FIG. 59. FIRST CLASS LEVER.

the effort (E). The effort arm (Ea) is made longer than the resistance arm (Ra), when this lever is used to gain mechanical advantage, because this arrangement makes the effort applied less than the resistance to be overcome. A pair of tin snips, Fig. 60, is a first class lever of this type.

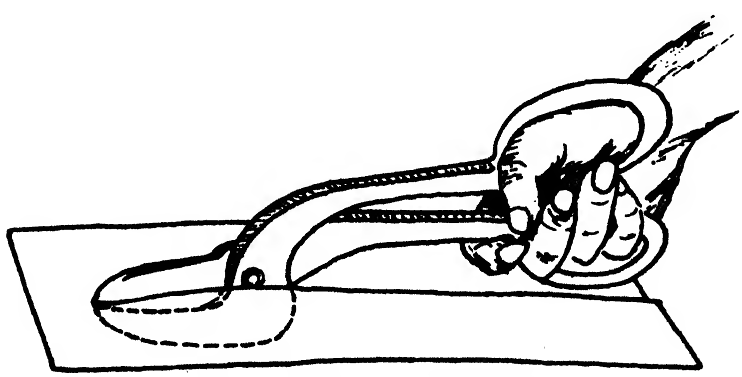


FIG. 60. "SLITTING" TIN SHEARS.

The handles (effort arm) are made longer than the cutting blades (resistance arm) so that the effort will be multiplied several times. The usual purpose in using a first class lever is to increase mechanical advantage, however, it may be used merely to change the direction in which the force acts. Fig. 61 shows the rocker arm of an automobile motor having overhead valves. This is an example of a first class lever used to change the direction of motion. If the effort arm is made shorter than the resistance arm, then a first class lever may be used to gain speed.

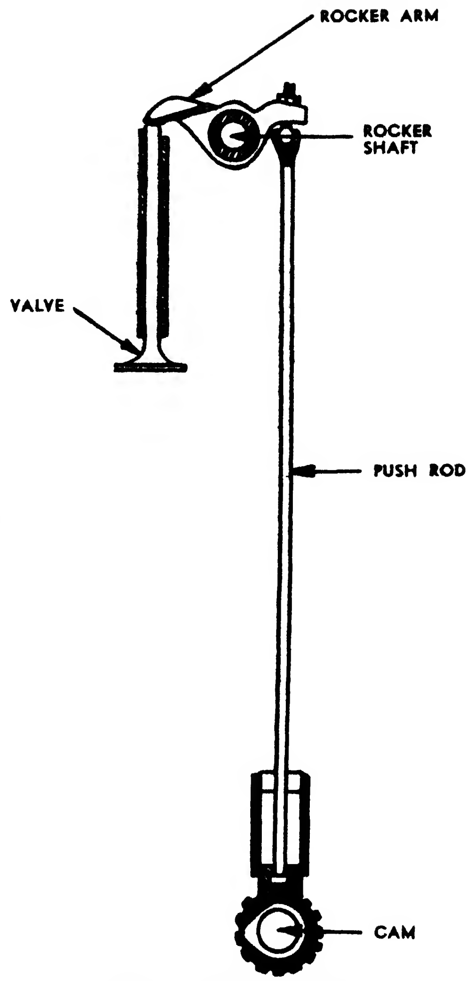


FIG. 61. ROCKER ARM.

A second class lever, Fig. 62, has the resistance between the effort and fulcrum. The effort is always less than the resistance to be overcome and moves in the same direction. A wheel barrow is a common example of such a lever.

The third class lever, Fig. 63, has the effort applied between the fulcrum and the resistance. This arrangement always requires an effort greater than the resistance and is used to gain speed. A man's arm is an example of this type of lever. Such a lever is also to be found in machines, the rocker arm of a shaper used in the machine shop being an application of this type of lever.

MECHANICAL ADVANTAGE

Since levers are usually used to multiply effort, it is often necessary to determine the mechanical advantage of a lever system. Mechanical ad-

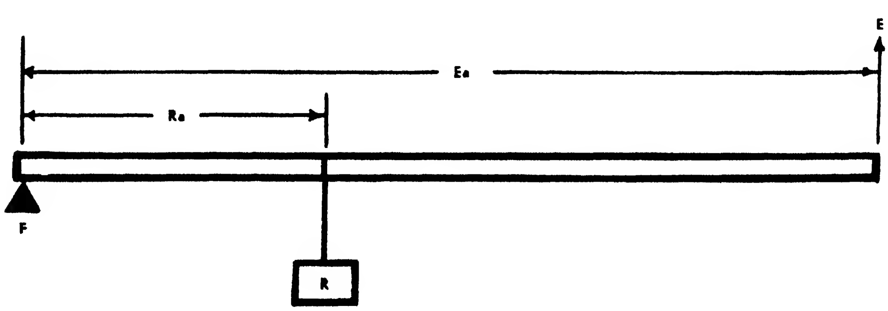


FIG. 62. SECOND CLASS LEVER.

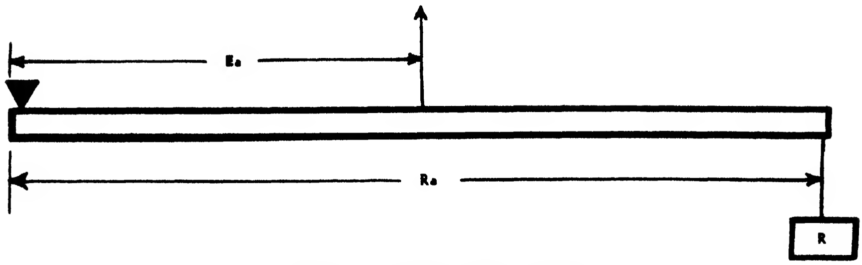


FIG. 63. THIRD CLASS LEVER.

vantage has been previously defined as a ratio between the resistance and the effort; or a number which shows how many times the resistance is greater than the effort used to overcome it.

The mechanical advantage of a lever may be determined by three methods.

First

As the ratio between the resistance and effort. (Actual M. A.)

$$\text{M. A.} = \frac{\text{R (resistance)}}{\text{E (effort)}}$$

Second

As the ratio between the effort arm and resistance arm. (Ideal M. A.)

$$\text{M. A.} = \frac{\text{Ea (effort arm)}}{\text{Ra (resistance arm)}}$$

The effort and resistance arms are the perpendicular distances from the fulcrum to the line of direction in which the effort and resistance move.

Third

As the ratio between the distance the effort moves and the distance the resistance moves. This is called velocity ratio — V. R.

$$\text{M. A.} = \frac{\text{De (effort distance)}}{\text{Dr (resistance distance)}}$$

LAW OF THE LEVER

The law of the lever is sometimes known as the "principle of moments." A *moment* is the *product* of a force and its perpendicular disdance from the fulcrum. (See Fig. 64.) When a lever is in equilibrium (not rotating) the sum of the *clockwise* moments must equal the sum of the *counterclockwise* moments. Algebraically this is stated

$$\text{E x Ea} = \text{R x Ra}$$

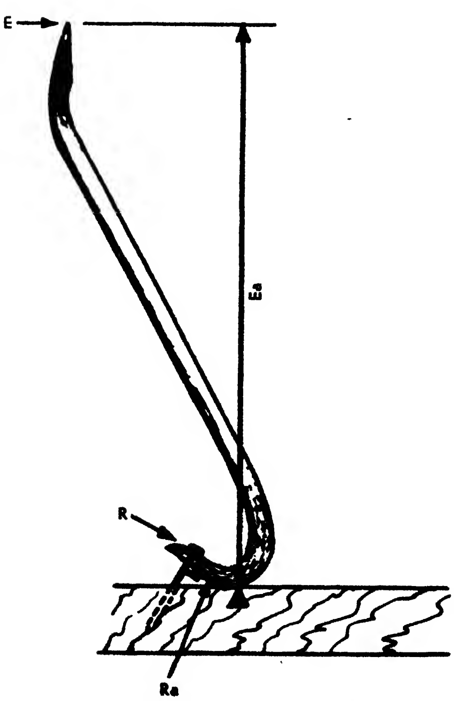


FIG. 64. BENT LEVER.

Where E = effort; Ea = effort arm; R = resistance and Ra = resistance arm.

When three of these quantities are known, the fourth is easily found by the use of the preceding formula.

EFFICIENCY

The efficiency of a machine is the ratio of its output to its input.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

Input is the amount of work done on the machine by an outside force while output is the amount of work that the machine delivers. Output is always less than input, due to friction, therefore efficiency is always less than 100%.

A lever resting on a hardened steel knife edge is almost frictionless, therefore it's efficiency may be very high. The lever follows the practical law of machines previously studied, that is, the effort (E) x the distance (D) through which E acts x efficiency = the resistance (R) x the distance (D) through which R moves in the same period of time.

New Words:

CLOCKWISE.—Moving in the direction in which the hands of a clock rotate.

COUNTERCLOCKWISE.—Moving in a direction opposite to that in which the hands of a clock rotate.

Additional New Words:

______ ....

....

______ ....

....

______ ....

....

EXPERIMENTING WITH LEVERS

Purpose:

1. To investigate the "Law of Levers."
2. To study the various classes of levers, observing many of their applications.

Tools and Materials:

Meter stick (or wooden bar)	Spring balance
Fulcrum and support	Heavy cord string
Weights (English or metric)	Linen thread

Procedure:

a) First Class Lever

Place the fulcrum at exactly the 50 cm. mark on the meter stick. Balance the stick on the fulcrum by placing a small strip of lead in the

proper place on the lighter end. Thus balanced, the weight of the lever can be disregarded in working this experiment.

By means of a linen thread, make short loops to hold the weights on the lever bar. Place weights of different sizes on the bar, one on each side of the fulcrum as shown in Fig. 65. Use the lighter weight as the effort

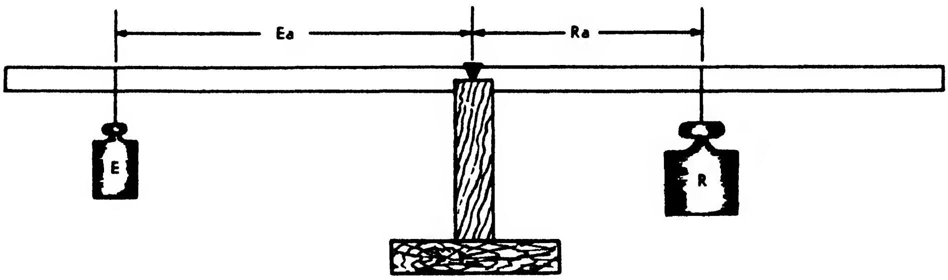


FIG. 65. FIRST CLASS LEVER.

and adjust the position of the weights until the lever balances. Repeat the experiment by placing both weights in a different position.

Place two weights (E and E′) on one side of the fulcrum (in different positions) and balance with one weight (R) on the opposite side. Note—This is similar to two men lifting a weight with a "crowbar." Record all these measurements in the Table XXII and complete the calculations.

	E	*Ea*	*E'*	*E'a*	*R*	*Ra*	*Moments*			*Mechanical advantage*	
							RxRa	*ExEa*	*Diff.*	*R/E*	*Ea/Ra*
1.			—	—							
2.			—	—							
3.							*Total*	*E* *E'*			

TABLE XXII

b) Second Class Levers

Arrange the lever as shown in Fig. 66. Keep the fulcrum at the center of the stick so that the weight of the lever need not be considered. Use a 500 g. (or 1 lb.) weight for the resistance and adjust the balance so that the lever will be horizontal. Record your measurements in Table XXIII and complete the calculations.

Repeat the preceding experiment, changing the positions of the resistance and effort.

	R	*Ra*	*E*	*Ea*	*Moments*			*Mechanical Advantage*	
					RxRa	*ExEa*	*Diff.*	*R/E*	*Ea/Ra*
1.									
2.									

TABLE XXIII

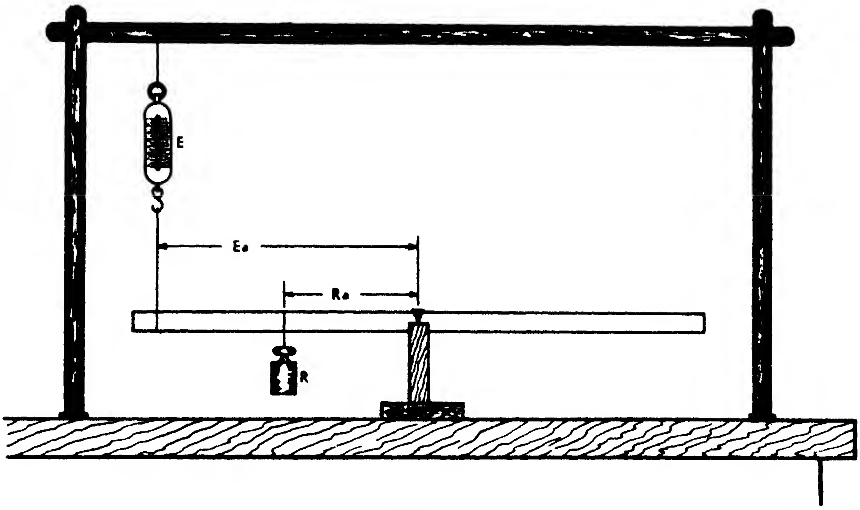


FIG. 66. SECOND CLASS LEVER.

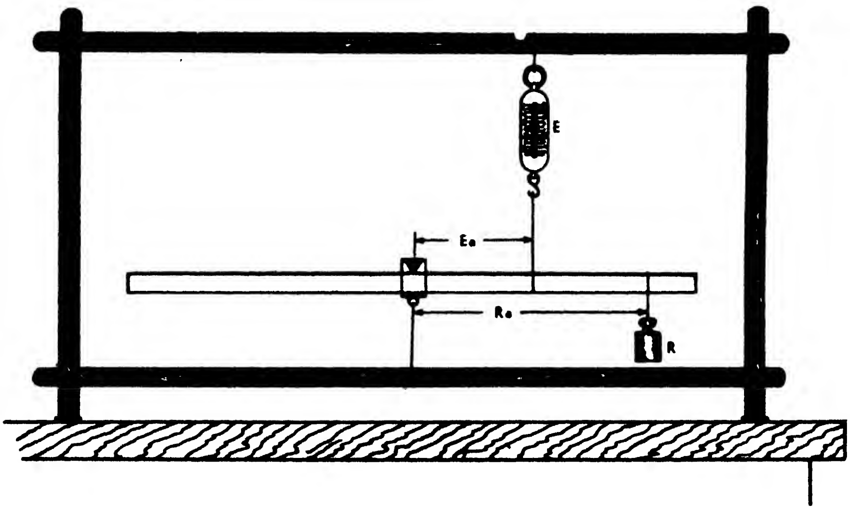


FIG. 67. THIRD CLASS LEVER.

c) Third Class Levers

Arrange the apparatus as shown in Fig. 67, fastening the fulcrum to a string from below. Adjust the lever to a horizontal position before taking the readings. Complete Table XXIV. Make a second trial, placing the weights in different positions.

	R	*Ra*	*E*	*Ea*	*Moments*			*Mechanical Advantage*	
					RxRa	*ExEa*	*Diff.*	*R/E*	*Ea/Ra*
1.									
2.									

TABLE XXIV

FIG. 68A. HAND TRUCK.

CLASS ....

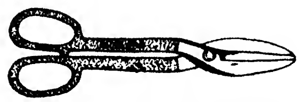


FIG. 68B. TIN SHEARS.

CLASS ....

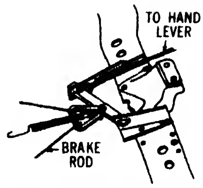


FIG. 68C. EMERGENCY BRAKE.

CLASS ....

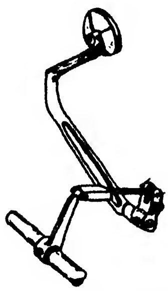


FIG. 68D. CLUTCH PEDAL.

CLASS ....

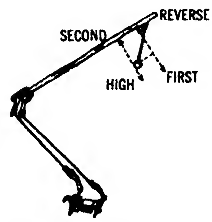


FIG. 68E. GEAR SHIFT.

CLASS ....

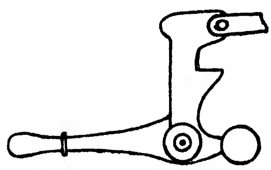


FIG. 68F. PLANER CLUTCH LEVER.

CLASS ....

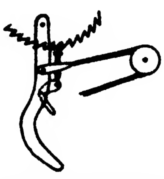


FIG. 68G. EMERGENCY BRAKE LEVER.

CLASS ....

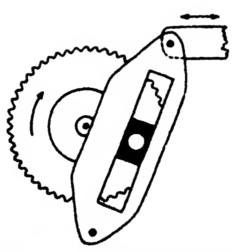


FIG. 68H. SHAPER ROCKER ARM.

CLASS ....

The pictures in Fig. 68 show various levers used in the shops. Name the class or classes to which each lever belongs.

Questions and Problems:

1. The results of these experiments show that lever(s) of the .... class sacrifice speed for force while lever(s) of the .... sacrifice force for speed.

2. When a lever is in equilibrium (balance) the clockwise moments........ .... the counterclockwise moments. This statement is known as the "..".

3. What is the "Law of the Lever"? ....

4. Which class of levers has a M. A. of less than 1? .... What does this mean? ....

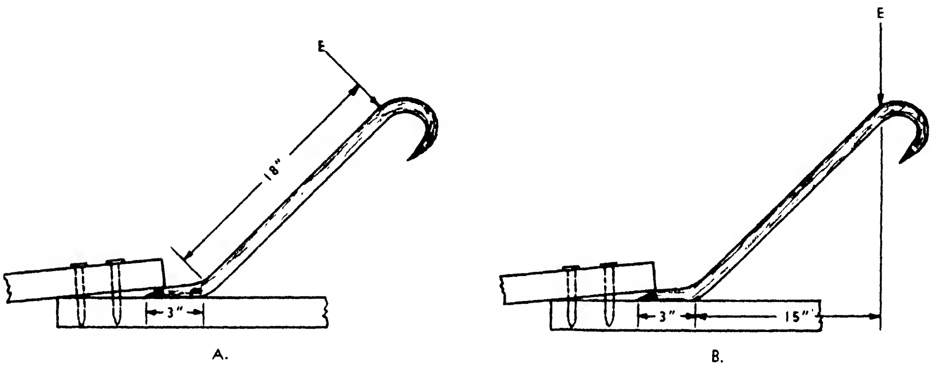


FIG. 69. WRECKING BAR AS LEVER.

5. If the nails in the boards, Fig. 69, offer a resistance of 300 lbs., what force is required to pull them in (a)? In (b)?

a)

b)

Why is the effort arm shorter in (b) Fig. 69? ....

6. Find the M. A. of the wrecking bar as used in problem 5.

(a) (b)

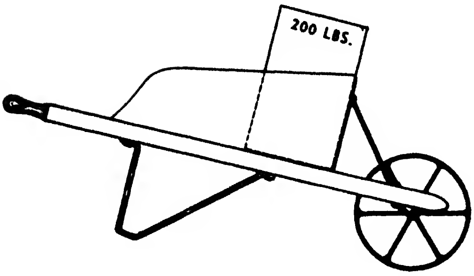


FIG. 70. WHEELBARROW.

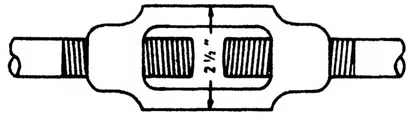


FIG. 71. TURNBUCKLE.

7. A box weighing 200 lbs. is being moved in a wheel barrow, Fig. 70. The load is 18″ from the axle of the wheel and the hands are 4½′ from the axle. Make an accurate diagram and calculate (a) the effort needed to lift the handles (b) the M. A.

8. A turnbuckle, Fig. 71, on a large draw rod is 2½″ across. A mechanic tightens this turnbuckle with a wrench having a 16″ handle. If he exerts a pull of 20 lbs. on the wrench (a) what resistance does the turnbuckle offer? (b) what is the M. A. of the wrench? Make a diagram showing to what class of levers this wrench belongs.

CENTER OF GRAVITY

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 30-33.
Dull: *Modern Physics*, pages 109-112; 127-130.
Fletcher: *Unified Physics*, pages 121-128.
Holley and Lohr: *Mastery Units in Physics*, pages 66-67.
Millikan: *New Elementary Physics*, pages 98-104.
Smith: *Mechanics*, pages 23-29.
U. S. Dept. of Commerce: *Civil Pilot Training Manual*, pages 30-42.

In our study of levers thus far we have considered the forces as acting at a single point and have disregarded the weight of the lever. Actually we know that the load distributes itself over a considerable area and does not act at a single point. Every material is composed of numberless particles, each of which has weight. Each particle is being attracted to the earth by the force of gravity. (See Fig. 72.) The center of gravity of most substances can be determined by balancing the body on a knife-edged support. When this point is found, the knife edge will push upward with a force equal to the sum of all the downward forces. This point, at which

all the weight of a body seems to be located, is called the *center of gravity.* If a body is suspended at its center of gravity it will have no tendency to rotate. (See Fig. 74C.) The center of gravity of a regular, homogeneous body, is at its geometric center. The center of gravity of irregular bodies must be found experimentally (for small objects) or mathematically by the principle of area moments (for large objects).

In the designing, building and loading of an airplane, the proper location of the center of gravity is of great importance. The forces which act on an airplane in flight, act at its center of gravity. (See Fig. 73.)

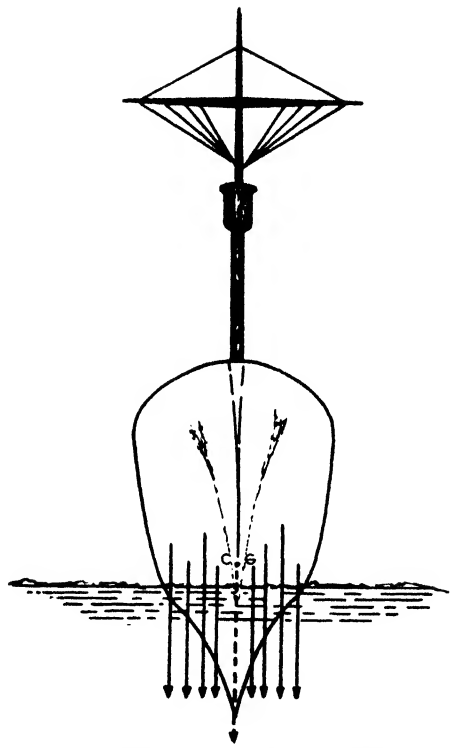


FIG. 72. FORCES AT CENTER OF GRAVITY.

EQUILIBRIUM

Bodies which are in a state of rest or motion possess *stability* when all

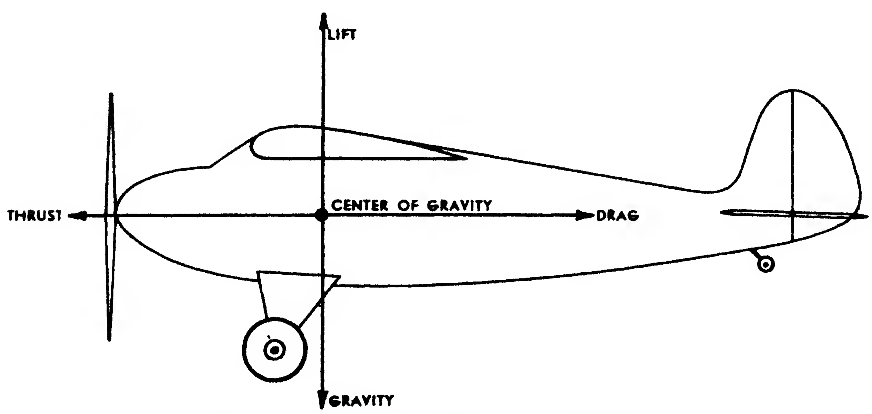


FIG. 73. FORCES ACTING ON AN AIRPLANE.

forces and moments are balanced. A body at rest is said to be in stable equilibrium when a line drawn from its center of gravity passes through its supporting base. Should this line fall outside the supporting base, the body is unstable and motion results.

Three kinds of stability are recognized, namely:

1. positive (stable), 2. neutral, and 3. negative (unstable). Fig 74 (A, B, C) illustrate these. If the triangle, Fig. 74A is moved it will assume

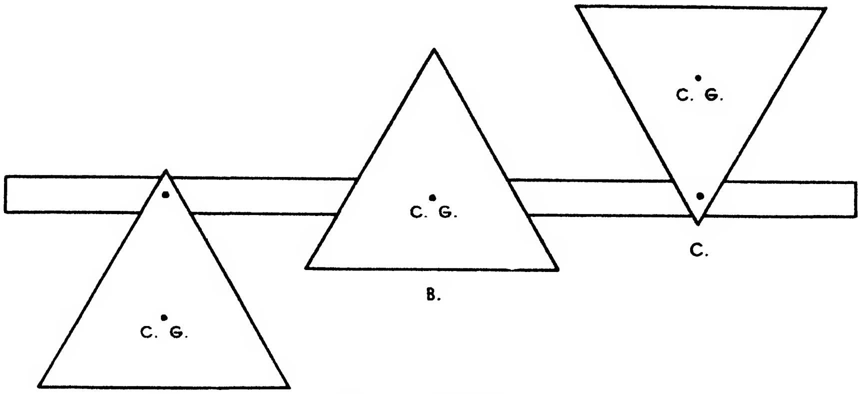


FIG. 74. STABILITY.

its original (stable) position when the moving force is withdrawn. This is because the center of gravity was raised as it moved from its original position. A body is said to be in *positive or stable equilibrium* if moving it necessitates raising its center of gravity.

The triangle, Fig. 74B, is unstable, because any motion will lower its

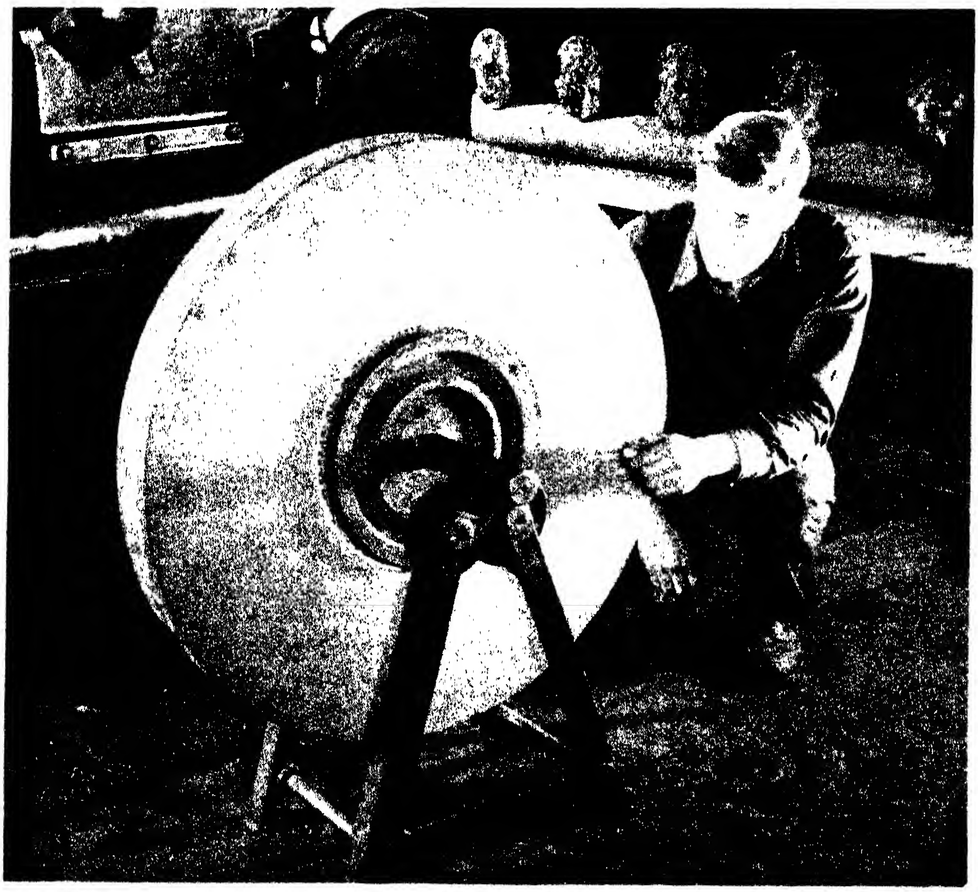


FIG. 74D. BALANCING A GRINDING WHEEL. (Courtesy, Carborundum Company.)

center of gravity, causing it to fall. A body is said to be in *unstable* equilibrium when motion causes its center of gravity to fall.

The triangle, Fig. 74C is in neutral equilibrium because it is balanced at its center of gravity. Any movement of it will not raise or lower its center of gravity. A rolling wheel is a common example of neutral stability. An important application of neutral equilibrium is the balancing of grinding wheels. Fig. 74D shows the equipment used in balancing a large grinding wheel. The balancing of such wheels is a necessity for perfection of grinding and as a safety precaution.

The stability of a body is measured by the amount of work necessary to overturn it. This is calculated by multiplying the weight of the body by

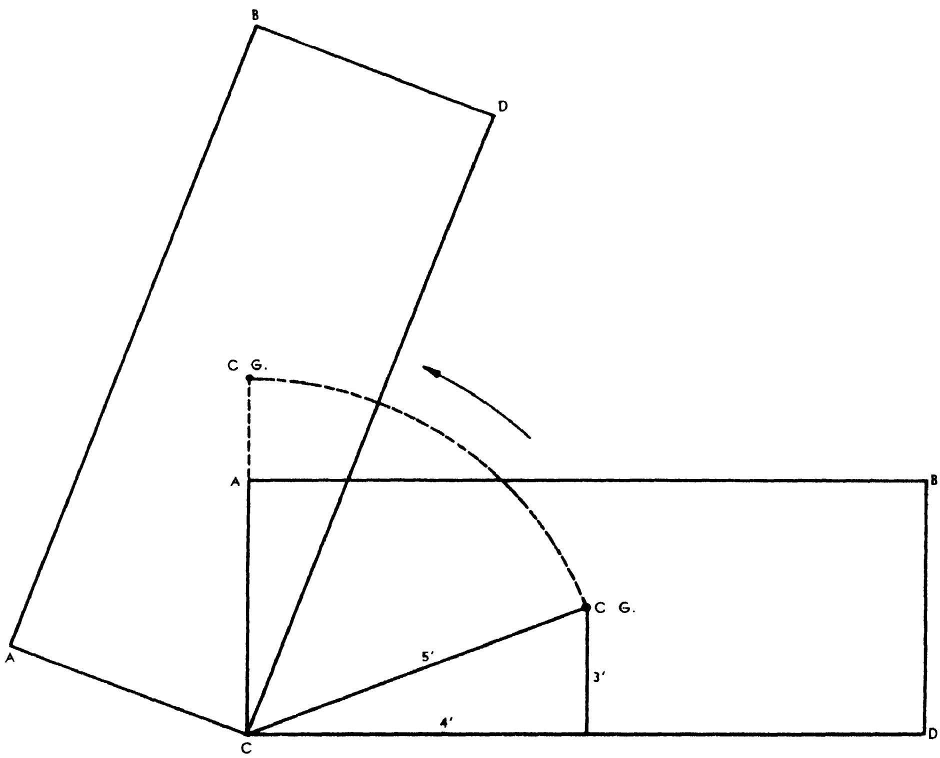
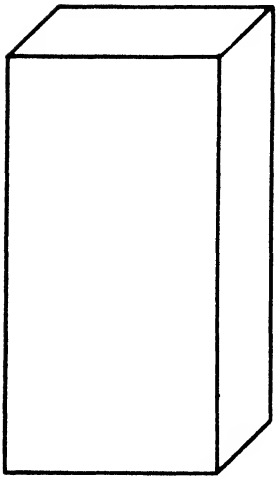
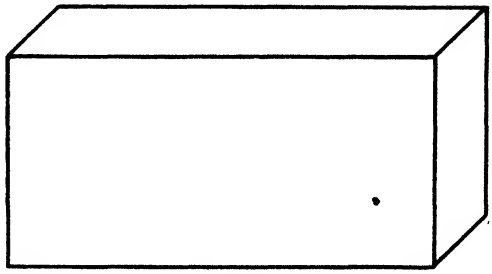


FIG. 75. MEASURE OF STABILITY.

the distance the center of gravity is raised in overturning it. This is illustrated by Fig. 75. When the box ABCD is turned on corner C, the center of gravity is raised two feet (5-3). If a 20 lb. effort is required to tilt the box, the work done is 20 x 2 or 40 foot pounds. The body is said to have a stability of 40 foot pounds.

In Fig. 76A, a brick is shown resting on end. In Fig. 76B the same brick is shown resting on its largest face. The latter has greater stability because of its broader base and lower center of gravity.





A B

FIG. 76. BRICK ON END AND SIDE.

GRAVITATIONAL FORCES

Purpose:

1. To understand the meaning of the terms gravitation, gravity and weight.
2. To determine the center of gravity by experiment and by geometry. To study the effect of the weight of levers on their force moments.
3. To learn the conditions affecting the stability of a body. To understand the three types of stability.

Tools and Materials:

Irregular or weighted bar	Irregular piece of sheet iron
Knife edge clamp	Scotch tape
String	Plumb bob
Set of weights	

Procedure:

a) The center of gravity of an irregular bar.

(Note: the bar used should not be symmetrical. A wooden bar weighted on one end is suitable to use.)

Balance the bar over a metal knife edge fastened to the edge of the table as shown in Fig. 77. Measure the location of this point (center of

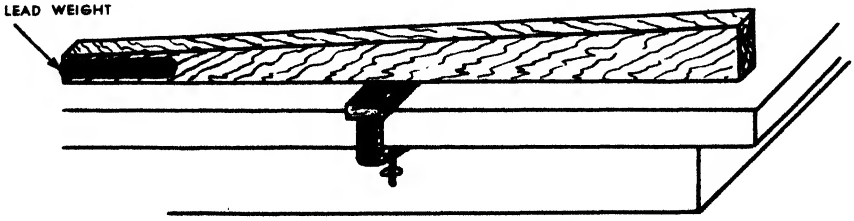


FIG. 77. CENTER OF GRAVITY OF IRREGULAR BAR.

gravity) from the ends of the bar. Now, by means of a string, hang a 500 g (or a 1 lb.) weight near the lighter end of the bar and rebalance it on the knife edge. Measure the new location of the fulcrum, i.e., its distance from the C. G. (Ra) and the distance to the weight (Ea).

Record

Distance of center of gravity from light end ....

Effort arm (Ea) ....

Resistance arm (Ra) ....

Using these measurements and the principle of moments, make a diagram and calculate the weight of the bar.

Weigh the bar accurately on a balance and compare this with the weight obtained by calculation.

Weight (by balance) .... (by calculation) ....

b) Center of gravity of an irregular sheet of metal.

Fasten sheet of paper to an irregular sheet of metal with cellulose tape. Trace the outline of the metal on the paper. Suspend the metal by means of a small nail placed through a hole near its edge. (See Fig. 78.) Hang a plumb line from the same nail. When the metal and nail have stopped swinging, accurately mark the position of the string on the paper. With a ruler and a sharp pencil, draw a line representing this position. Suspend the sheet from another hole and repeat the process.

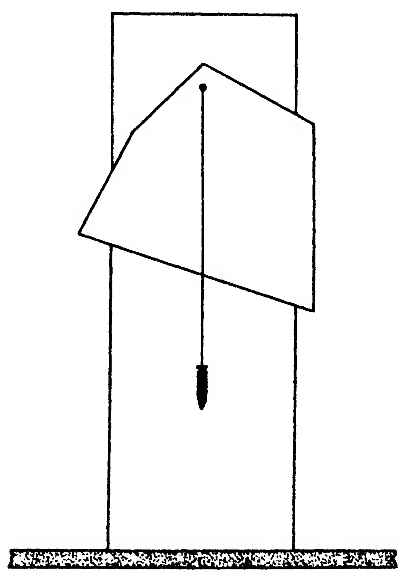


FIG. 78. CENTER OF GRAVITY OF PIECE OF METAL.

1. The point at which these lines cross is called the ....

   Since the metal has thickness, the .... actually lies ....

   Hang the metal from a third hole.

2. Does this string pass through the center of gravity? ....

3. In making this test, why is it necessary to suspend the sheet from

three different holes? ....

....

Remove the paper from the sheet of metal and place it in your book.

Questions and Problems:

1. Write definitions for the following terms.

    a) Gravity ....

    b) Gravitation ....

    c) Weight ....

2. What is meant by "center of gravity"? ....

    ....

3. Locate, by geometry, the center of gravity of the figures found in Fig. 79.

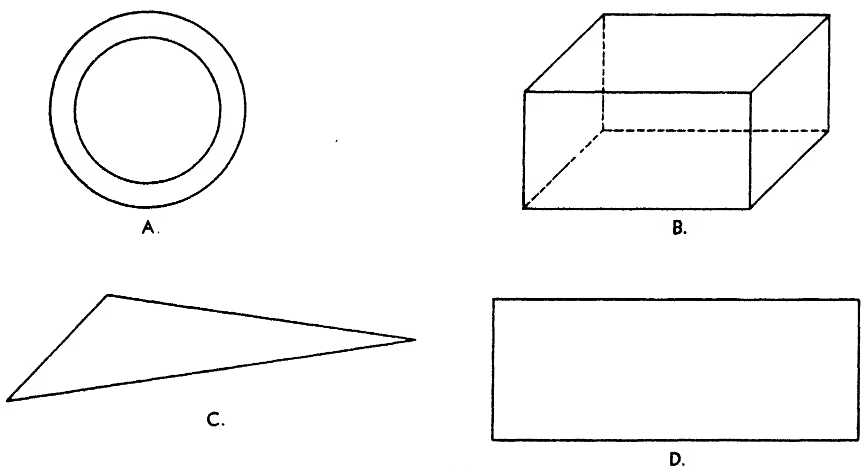


FIG. 79. CENTER OF GRAVITY BY GEOMETRY.

(Note: The axis of a rectangular solid is an imaginary line drawn from the center of one side to the center of the side opposite. The three axes of such a solid cross at its center of gravity. The axis of a cylinder is an imaginary line drawn through the center of one end to the center of the opposite end.)

4. What is meant by equilibrium? ....

    ....

Draw diagrams, illustrating the position of a spike nail when it is in stable, unstable and neutral equilibrium.

STABLE EQUILIBRIUM | UNSTABLE EQUILIBRIUM | NEUTRAL EQUILIBRIUM

5. Give two reasons why the automobile of today is more stable (harder to upset) than the models of twenty years ago.

   a) .... *b)* ....

6. A news item carried by the newspapers and datelined Feb. 17, 1941 follows: "A boat, sailing to England with a cargo of pig iron, overturned during a storm, due to the shifting of its cargo." Why did the shifting cargo cause the boat to upset? ....

   ....

7. Two boys push upward (at the same point on a pipe) as shown by (E), Fig. 80, with a force of 75 lbs. The pipe weighs 50 lbs. and is

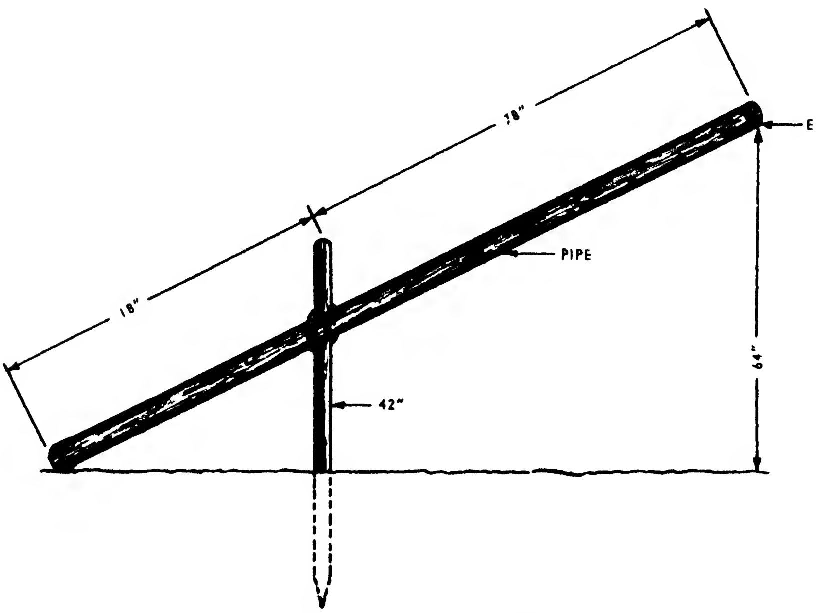


FIG. 80. PULLING A STAKE.

fastened by means of a chain to a stake in the ground. The chain is fastened 18″ from the end of the pipe. What resistance does the stake offer?
Make an accurate diagram and show calculations here.

Does the weight of the pipe help or hinder the boys? ....

8. What is the law of universal gravitation? ....

....

.... Illustrate with an example.

....

9. Why is a truck loaded with 5 tons of hay less stable than one loaded with 5 tons of bricks? ....

10. Fig. 81 shows a test which must be made on a motor armature. What kind of a test is this? ....
What is its purpose? ....

FIG. 81. BALANCE OF AN ARMATURE.

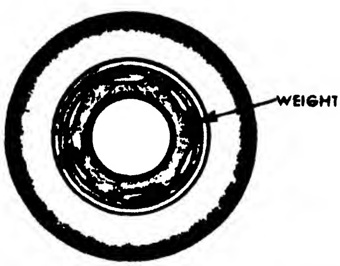


FIG. 82. BALANCING WEIGHTS OF AUTOMOBILE WHEEL.

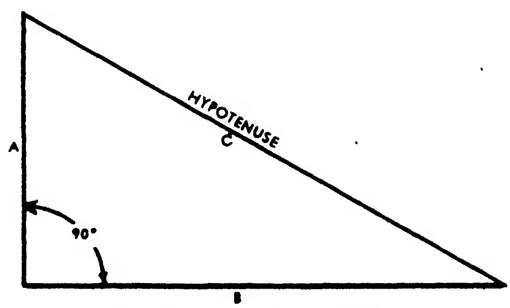


FIG. 83. RIGHT TRIANGLE.

11. Weights are sometimes placed on automobile wheels as shown in Fig. 82. *a)* What caused the wheel to need weights? ....

....

b) How do these weights correct the trouble? ....

....

Fig. 83 gives some facts from geometry which are needed in solving the next problems. In a right triangle, the side opposite the right

angle is called the hypotenuse. The square on the hypotenuse is equal to the sum of the squares of the other two sides (legs).

$$C^2 = A^2 + B^2$$

12. A crated refrigerator 4′ x 3′ x 7′, is being hauled on a truck. Make diagrams and explain why it will be more stable lying on its back than standing on end.

13. In problem 12, if the center of gravity of the crate is its geometrical center, how high will the C. G. have to be lifted before the crate will overturn a) when it is standing on end? b) when on its side? Make accurate diagrams, using the information given in Fig. 83 to aid you in solving.

14. A small flag pole, Fig. 84, is 40 feet long. It balances when a block is placed under it 15 feet from the base. The pole weighs 600 pounds. How much force must be exerted to lift the small end off the ground. Make an accurate diagram and solve.

FIG. 84. FLAG POLE.

15. A crowbar is 4 feet long, weighs 8 lbs. and its center of gravity is 28″ from the tapered end. When used to pry a 2 x 4 loose, the bar is placed so that the fulcrum is 3″ from the end. When a force of 50 lbs. is exerted at the end of the bar, what prying force is being exerted?

Does the weight of the bar aid or hinder in prying the 2 x 4's apart?

....

PULLEY SYSTEMS

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 37-39; 63-65.
Dull: *Modern Physics*, pages 183-185.
Fletcher: *Unified Physics*, pages 152-155; 171-172.
Holley and Lohr: *Mastery Units in Physics*, pages 233-238.
Millikan: *New Elementary Physics, pages* 152- 155; 182-186.
Smith: *Mechanics*, pages 119-121.

Introduction:

A system of ropes and pulleys is commonly known as the "block and tackle." This is not a highly efficient machine because of the large amount of friction in its moving parts. A pulley, Fig. 85, consists of a frame, called the block or shell, and a grooved wheel (or wheels) called a sheave. The wheels turn freely on a fixed axle.

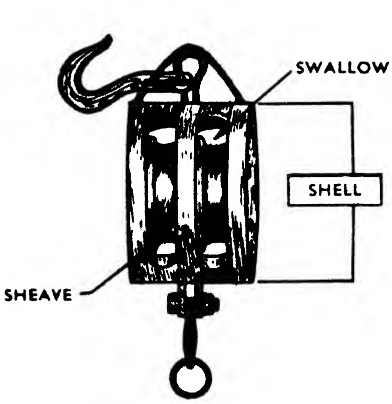


FIG. 85. PULLEY BLOCK

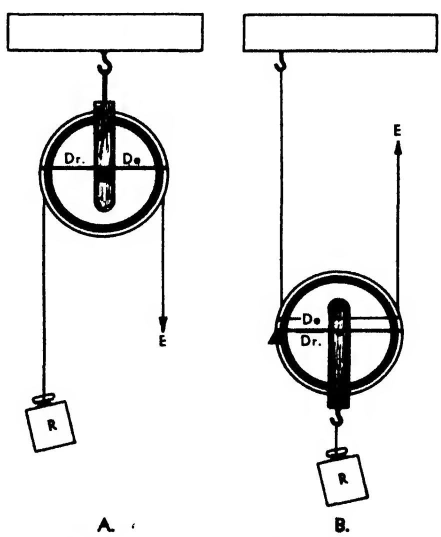


FIG. 86. PULLEYS ARE LEVERS.

Blocks, with several sheaves, usually have them placed side by side on the same axle. The sheaves, however, are usually arranged vertically when diagramming pulleys so that the method of stringing can be clearly shown. Pulleys may be used to gain great mechanical advantage or they may be used to change the direction in which the force acts. Pulleys are a modification of the lever principle. Drawing A, Fig. 86 shows how the single fixed pulley resembles a lever of the first class. Drawing B, Fig. 86 shows that a single movable pulley is a lever of the second class. In any pulley system, the fixed pulleys are first class levers serving to change the direction of motion while the movable pulleys are second class levers, each with a mechanical advantage of two.

The theoretical mechanical advantage of any pulley system can be ascertained by counting the number of ropes supporting the movable block. The actual mechanical advantage is the ratio of the resistance to the effort.

$$\text{M. A.} = \frac{R}{E}$$

The efficiency of a pulley system is found by the formula —

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

where the output is R x Dr (resistance x the distance the resistance moves) and the input is E x De (effort x the distance the effort moves). This formula may be restated thus —

$$\text{Efficiency} = \frac{R \times Dr}{E \times De}$$

EXPERIMENTING WITH PULLEY SYSTEMS

Purpose:

To study the mechanical advantage and efficiency of various arrangements of pulleys.

Tools and Materials:

- Two single pulleys
- Two double pulleys
- One triple pulley
- String
- Two weight hangers
- Slotted weights
- Brass weights
- Meter stick
- Spring balance

Procedure:

Fasten a single pulley on a table support as shown in Fig. 87. Run a cord over the sheave and attach a weight hanger to each end of the cord. Place a load of 500 g. on one of the hangers and add just enough weight to the other to raise the load slowly. Be sure to include the weight of the hangers in figuring the total loads. Record the force required to lift the load as (E + f), since part of the effort is used in overcoming friction.

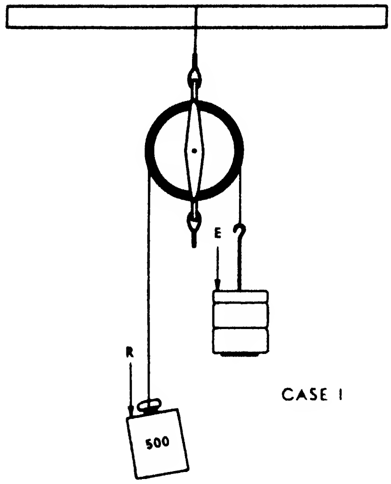


FIG. 87. SINGLE FIXED PULLEY.

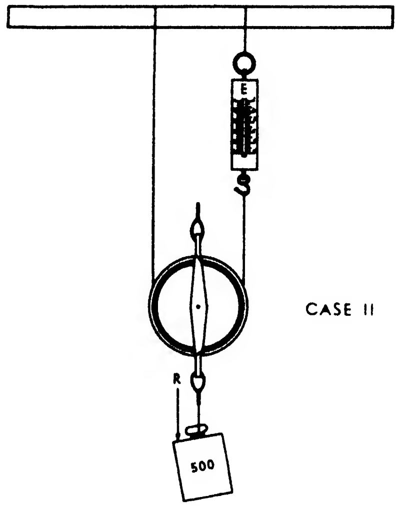


FIG. 88. SINGLE MOVABLE PULLEY.

Remove just enough weight to allow the load to move down slowly. This weight is (E - f). By averaging these readings, the effect of friction will be almost eliminated in the pulley system. Place a meter stick vertically back of R and another back of E. Move R 5 or 10 cm. and determine the distance E moves in the same period of time. Record all the results in Table XXV and make the calculations called for.

1. The distance the load was raised was (greater than, less than, equal to) .... the distance through which the effort moved.

2. The load raised was (greater than, less than, equal to) .... the effort.

Arrange the single pulley so that it moves with the load (see Fig. 88). Use a 1000 g. weight for the resistance (R). Weigh a movable pulley and include its weight as part of the resistance. With a meter stick, measure the distance the effort moves when the resistance is moved 5 or 10 cm. Record all results in Table XXV.

3. The distance through which the effort moves is (twice, half, equal to) .... the distance the resistance moves.

4. The load is (twice, half, equal to) .... the effort used to raise it.

Set up the arrangement of pulleys shown in Fig. 89. using the weights specified in the drawings. Carry out tests as in the previous cases.

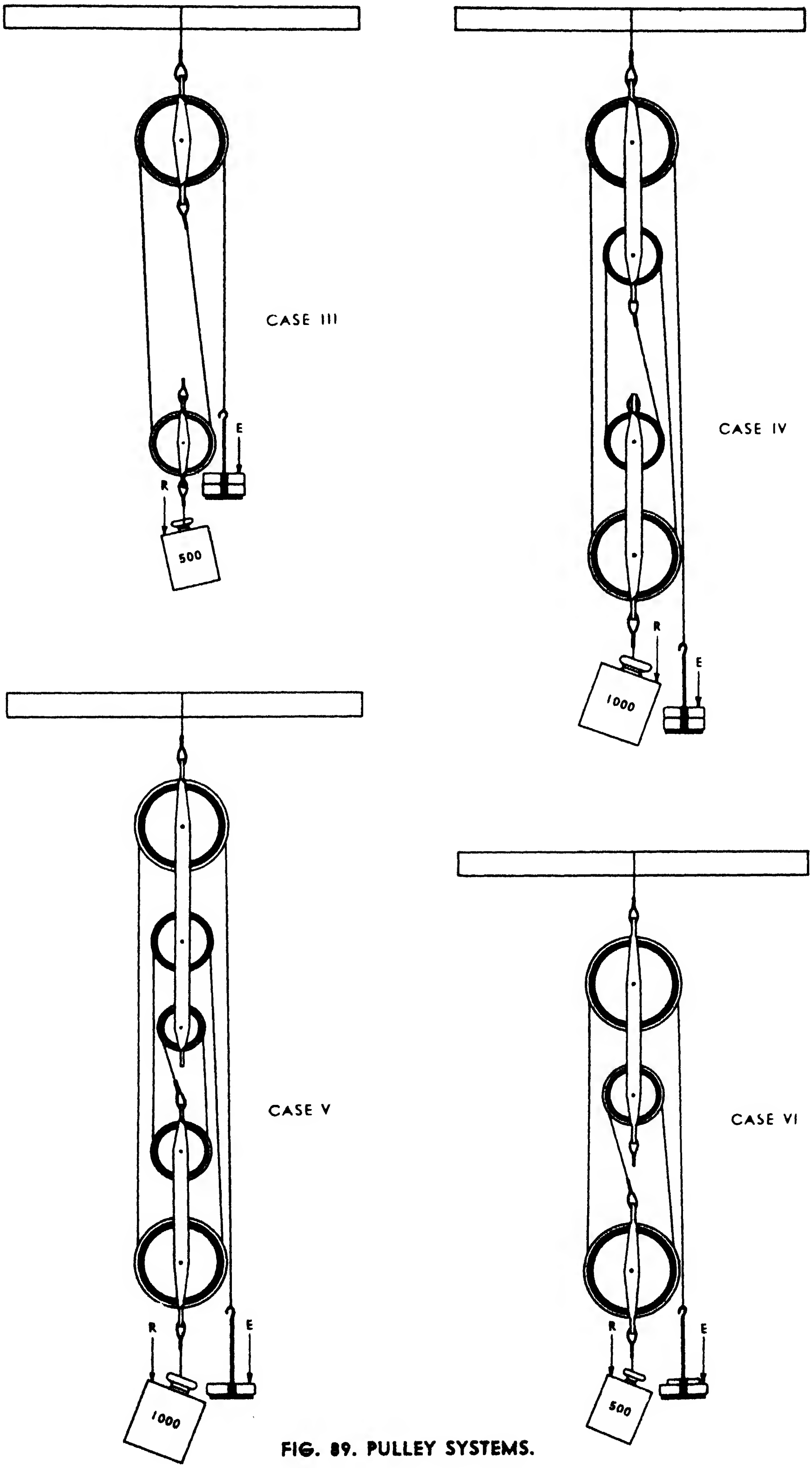


FIG. 89. PULLEY SYSTEMS.

Case	Weight of Load	Pan	Mov. Block	Total (R)	E + f	E − f	Ave E	Distance moved R	E
I									
II						——			
III									
IV									
V									
VI									

Case	Work* Input	Output	Velocity Ratio	Mech. Adv.	Efficiency*
I					
II					
III					
IV					
V					
VI					

TABLE XXV

* Note — In caculating the work input, multiply the effort (E + f values) by the distance through which it moves: Output is obtained by multiplying the load (do not include the weight of the movable block) by the distance through which it moves: Efficiency is found by dividing the output by the input, then multiplying the quotient by 100 to obtain it in percentage.

Questions and Problems:

1. How can the mechanical advantage of a set of pulleys be determined by observation? ....

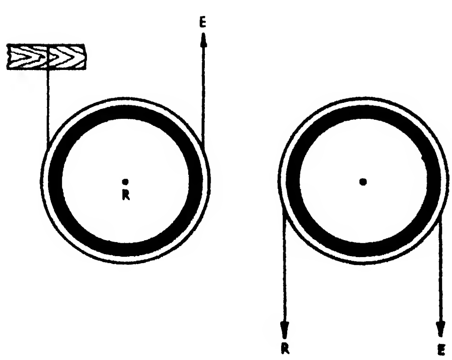


FIG. 90. PULLEYS AS LEVERS.

2. A single fixed pulley and single movable pulley may be considered as levers. In Fig. 90, draw lever diagrams within the pulleys, labelling F, E and R clearly. Tell to which class of levers each belongs.

3. Make a diagram in the following space showing a pulley system that can lift a load of 540 pounds with an effort of 90 pounds. Disregard friction.

How much rope will be drawn through the pulleys in lifting the weight 20 feet? ....

4. Which of the pulley arrangements in Fig. 91 will require the least effort to pull the gun up hill? Arrangement *a)* or *b)*?..

The M. A. of arrangement in *a) is* ....

Give a reason for your answer. ....

....

The M. A. of arrangement in *b)* is ....

Give a reason for your answer. ....

....

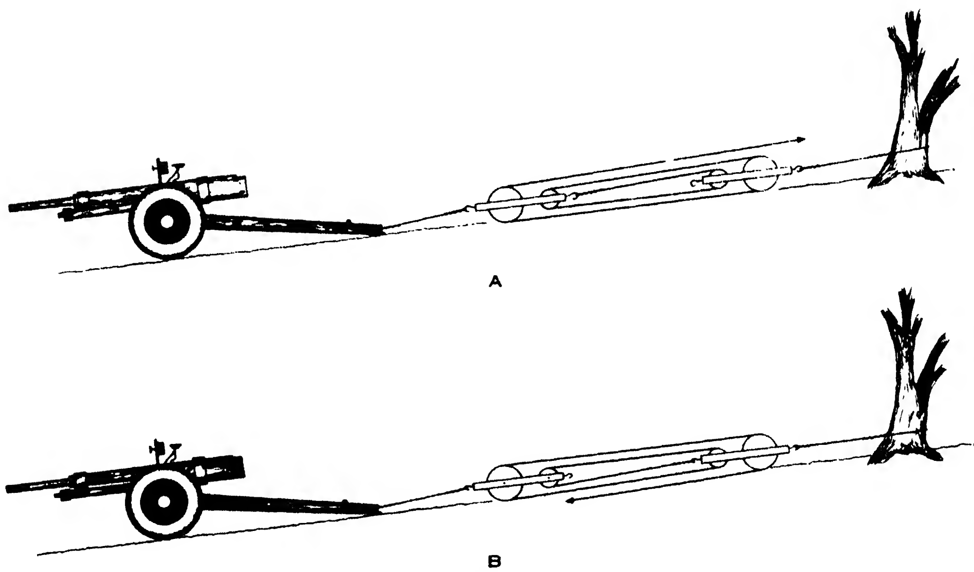


FIG. 91. BLOCK AND TACKLE PROBLEMS.

THE WHEEL AND AXLE

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 35-37; 51-58.
Dull: *Modern Physics*, pages 185-187; 191-197.
Fletcher: *Unified Physics*, pages 151; 154-155.
Holley and Lohr: *Mastery Units in Physics*, pages 236-240.
Millikan: *New Elementary Physics*, pages 163-165; 167-168.
Smith: *Mechanics*, pages 121; 125-134; 142-160.

Purpose:

1. **To study the operating principle of the wheel and axle.**
2. **To understand how the mechanical advantage or velocity ratio of the wheel and axle is calculated.**

3. To find applications of the wheel and axle in various machines.

Introduction:

The wheel and axle has many applications in shop and industrial machinery. Belted pulleys and gear trains apply the wheel and axle principle. This simple machine consists of two or more fixed pulleys of different diameters rigidly attached to the same shaft. The windlass, used to lift wrecked automobiles, is a good example of the wheel and axle. The wheel and axle is most often used to gain mechanical advantage but may be used to gain speed, as in turning the drive wheel of an automobile or bicycle.

Tools and Materials:

Wheel and axle	Strong cord
Weights	Weight hanger
Meter stick	Outside calipers
Differential pulley	Spring balance

Procedure:

Clamp the wheel and axle to the table upright support as shown in Fig. 92. The wheel of the smallest diameter is to be considered the axle in all trials to be made in this experiment, the other diameters to be used as the various wheels. Wind at least one full turn of cord on the axle, then

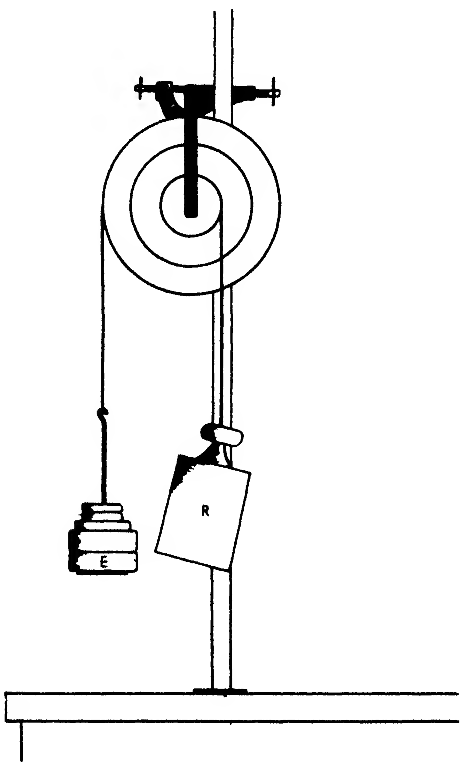


FIG. 92. WHEEL AND AXLE.

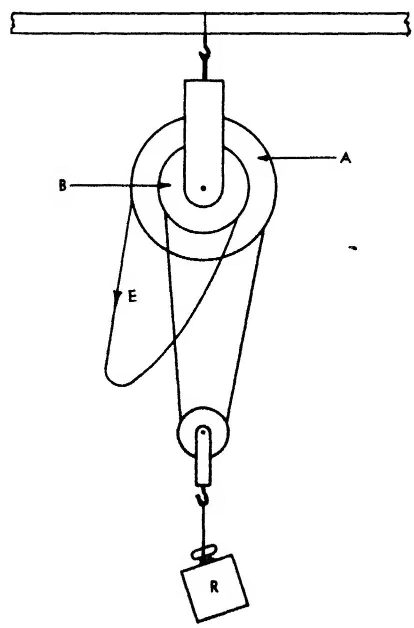


FIG. 93. DIFFERENTIAL PULLEY.

by means of a loop, hang a 1000 g. weight on the free end of the cord. Attach a cord to the largest wheel and wind at least two turns around it. Place a weight hanger on the free end of the cord and add weights until the resistance (1000 g) is raised slowly and uniformly. Record this as (E + f), being sure that you include the weight of the hanger in the total effort. Remove enough weight from the hanger so that the resistance is slowly lowered. Record this as (E – f). The average of these two readings will be the force required when friction is eliminated. Place a meter stick back of the effort and resistance, then move the effort 10 or 20 cm. Measure the distance the resistance moves during the same period of time.

Use the remaining wheels and repeat these tests. Accurately measure the diameters of the wheels and axle, using an outside caliper and steel rule. Record all observations and calculations in Table XXVI.

Trial	*Effort*		*Resist.*	*Actual M. A.*	*Diameter*		*Theoretical M. A.*
	E + f	*E – f*	*R*	*R/E*	*Wheel*	*Axle*	*Dw/Da*
I							
II							
III							

Trial	*Distance moved*		*Ideal M. A.*	*Work**		*Efficiency*	
	R	*E*	*De/Dr*	*Input*	*Output*	*Input*	*Output*
I							
II							
III							

* Use E + f figures for input calculation.

TABLE XXVI

How do the mechanical advantages as found by the different methods compare? ....

Explain any difference found. ....

....

DIFFERENTIAL CHAIN PULLEY

Introduction:

The differential pulley is a compound machine which uses two sheaves of slightly different diameters in the upper block and a single movable pulley for the lower block. The sheaves in the upper block are cast in one piece (a wheel and axle) with pockets or sprockets in them to prevent the endless chain from slipping, thus when the effort is removed, the friction is great enough to keep the load from moving backward.

The M. A. (or V. R.) of the differential pulley is determined by using the formula —

$$\text{M. A.} = \frac{2A}{A - B}$$

where A is the circumference (or number of teeth) of the larger of the upper sheaves and B is the circumference (or number of teeth) of the smaller sheave. (See Fig. 93.) A study of the differential pulley in operation shows that as the effort winds chain on the larger sheave equal to A, chain equal to B is unwound on the smaller sheave. Thus the chain is shortened (A – B) inches or links. The lower block, being a single movable pulley with a M. A. of two, causes the resistance R to be lifted only $\frac{1}{2}$(A – B), hence the formula De/Dr becomes

$$\frac{A}{\frac{1}{2}A - B} \quad \text{or} \quad \frac{2A}{A - B}$$

Demonstration:

FIG. 94. A DIFFERENTIAL PULLEY IN USE.

Set up a differential pulley (laboratory or commercial model) as shown in Fig. 94. If a commercial type is used, use heavier weights than called for in this experiment.

Count the number of chain pockets or sprockets in the two upper sheaves. Using the formula given in the introductory paragraph, calculate the V. R. of the machine, placing the results in Table XXVII. Check the theoretical V. R. thus found with the actual V. R., by measuring the distance the effort moves (De) with the distance the resistance moves (Dr) in the same period of time.

$$\text{Actual V. R.} = \frac{De}{Dr}$$

Using a spring balance, determine the effort needed to raise the movable block, without load; then with a load of 500 g.; 1000 g.; 1500g.; 2000g.; 2500g. and 3000g., recording each time the effort needed to lift the load R. Also calculate the input, output and efficiency for each trial. Complete Table XXVII, then make a graph in Fig. 95 showing the relationship of the effort and efficiency to the size of the load.

Label each curve, i. e., effort and efficiency.

a) Chain sprockets (or pockets) in large sheave ....

b) Chain sprockets (or pockets) in small sheave............

c) Theoretical velocity ratio $\frac{2A}{A - B}$ = ____________ = ____________

d) Actual velocity ratio = De/Dr = ________ ÷ ________ = ________

Load	*Effort*	*Velocity Ratio*	*Input*	*Output*	*Efficiency*
0					
500					
1000					
1500					
2000					
2500					
3000					

TABLE XXVII

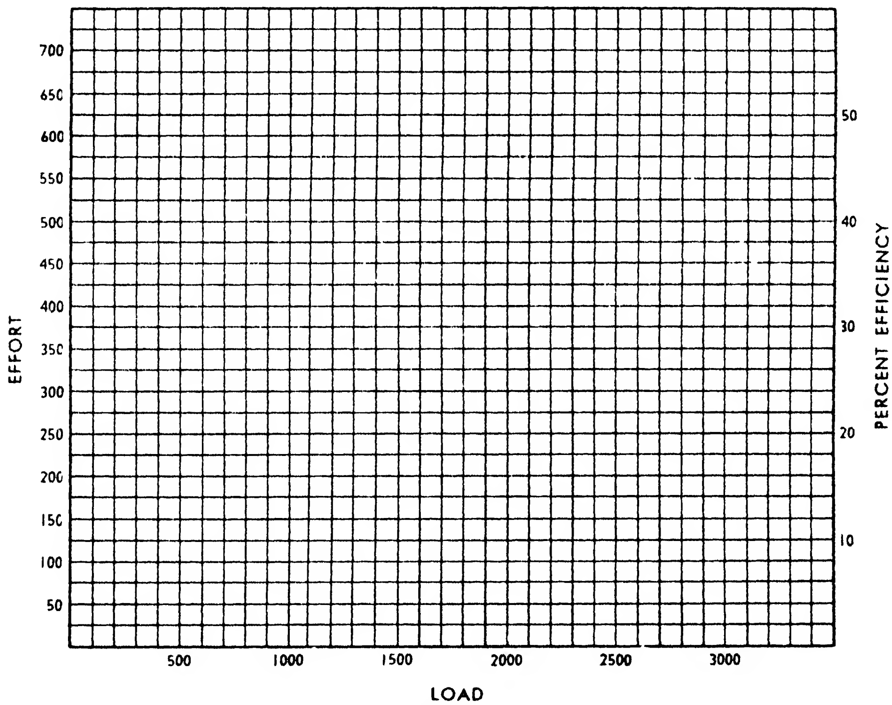


FIG. 95.

Questions:

1. Name ten common applications of the wheel and axle.

a) .... *f)* ....

b) .... *g)* ....

c) .... *h)* ....

d) .... *i)* ....

e) .... *j)* ....

2. State the "law of the wheel and axle." ....

....

3. In using a wheel and axle, how many revolutions does the axle make when the wheel makes one complete turn? ....

4. (Force, speed) .... is generally lost in the use of the wheel and axle while .... is gained.

5. Complete the diagram in Fig. 96, to show that the wheel and axle is

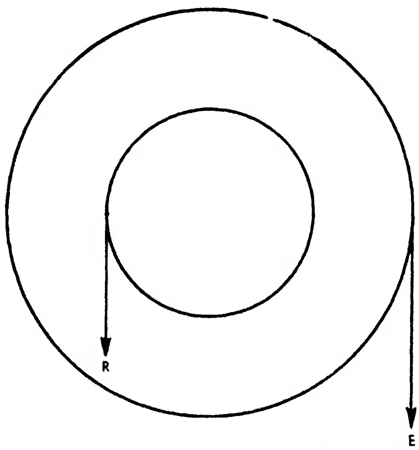


FIG. 96. WHEEL AND AXLE AS A LEVER.

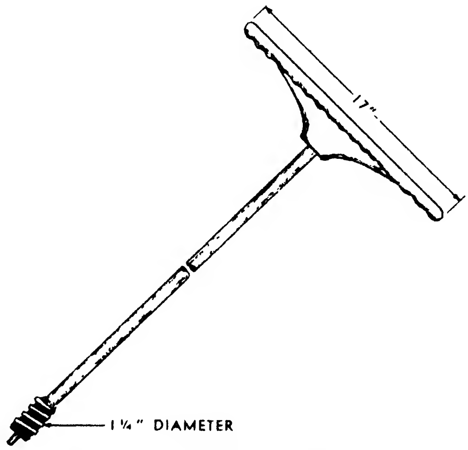


FIG. 97. STEERING WHEEL.

in reality a lever. To what class of levers does it belong? ....

6. Calculate the V.R. of the automobile steering wheel shown in Fig. 97.

7. The (front, rear) .... wheel of an automobile uses the wheel and axle principle. In this case, the wheel and axle is used to gain

....

THE INCLINED PLANE GROUP

REFERENCES

Black and Davis: *Elementary Practical Physics,* pages 46-51.
Dull: *Modern Physics,* pages 187-191.
Fletcher: *Unified Physics,* pages 156-159.
Holley and Lohr: *Mastery Units in Physics,* pages 220-223.
Millikan: *New Elementary Physics,* pages 165-167.
Smith: *Mechanics,* pages 122-124.

Introduction:

The ramp in a garage, the stairway in the home, and the inclined road are all common examples of the inclined plane. Many other examples

can be quickly called to mind. The inclined plane has mechanical advantage because the effort travels a greater distance than would be necessary if the weight or resistance were to be lifted vertically. Engineers speak of hilly roads as having certain "grades," such as a 3% grade. For roads with gradual inclines the grade is the ratio of the length of the road to its rise. (See (A) Fig. 98.) For steeper grades, the per cent of grade

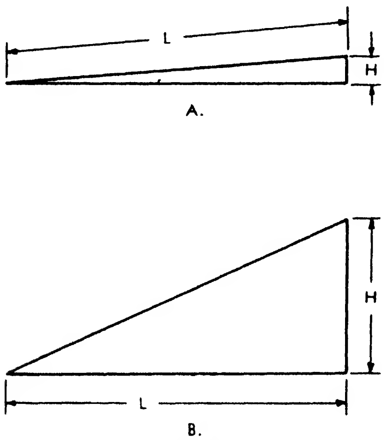


FIG. 98. INCLINED PLANE (Grade Problem).

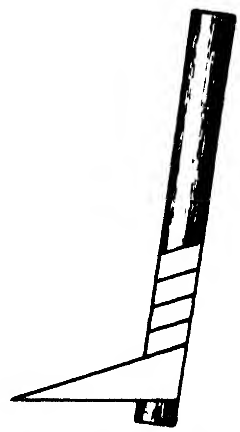


FIG. 99. A SCREW IS AN INCLINED PLANE.

is the ratio of the horizontal distance to the rise. (See (B) Fig. 98.) The mechanical advantage of the inclined plane is found by dividing the length by the height (L/H).

The screw, with numerous uses, is a modification of the inclined plane. This can be shown by cutting a small triangle (representing an inclined plane) out of paper and wrapping it around a small cylinder. (See Fig. 99.) Beside being used for holding all types of materials together or as a measuring instrument (micrometer), the screw is also used to lift heavy weights (the screw jack) because of its great mechanical advantage. The pitch of a screw is the distance measured from some point on one thread to a corresponding point on the next thread. The lead of a screw is the distance it advances in one revolution. The lead and pitch are the same for most screws (single thread screws).

The mechanical advantage of a screw jack, Fig. 100, is found by the formula —

$$\text{M. A.} = \frac{2\pi r}{p}$$

where r is the length of the handle
and p is the pitch of the screw

The wedge, Fig. 101A, is a double inclined plane. It differs from the plane in that it is moved rather than the weight or object being moved on the plane. The mechanical advantage of a wedge is found by dividing the length by the thickness. The longer the wedge as compared to its thickness, the greater will be its mechanical advantage. Since a wedge depends to a great extent on friction, it is difficult to formulate any exact

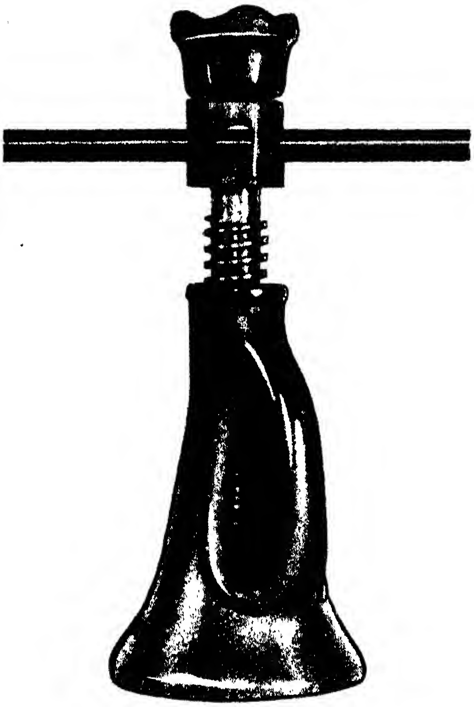


FIG. 100. SCREW JACK.

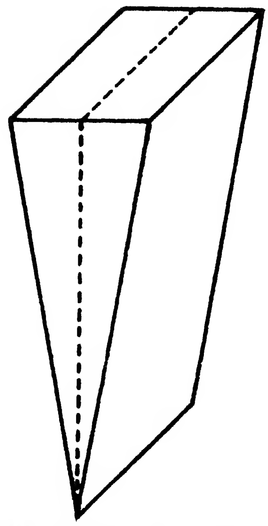


FIG. 101A. A WEDGE IS A DOUBLE INCLINED PLANE.

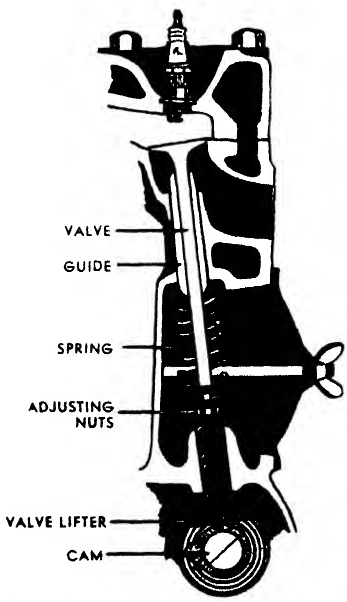


FIG. 101B. A CAM IS A ROTATING INCLINED PLANE.

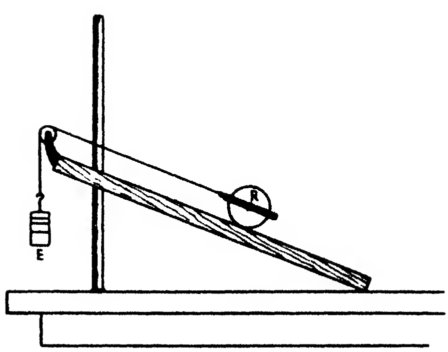


FIG. 102. INCLINED PLANE.

laws concerning it. The cam is a device using the inclined plane principle. Fig. 101B illustrates a cam as used in an automobile engine for opening intake and exhaust valves.

THE INCLINED PLANE

Purpose:

To calculate the mechanical advantage of an inclined plane.

Tools and Materials:

Inclined plane board and pulley
Car (Hall's carriage) or roller
Weights and weight hanger
String
Meter stick

Procedure:

Clamp the inclined plane board to the table support as shown in Fig. 102, making the angle with the table top about 25°. Weigh the car or roller, place it on the board and guide the string over the pulley sheave at the top of the board. (If a car is used, place about 1500 g. of weight in it.) Add weights to the weight hanger until the car or roller moves slowly and uniformly up the incline. Record this weight in Table XXVIII as (E + f) force plus friction. Now move sufficient weights until the car moves slowly and uniformly down the incline. Record this as (E – f). Averaging these forces will eliminate friction from the calculations. Measure the height and length of the plane. This can be easily done by measuring the lower edge of the board.

Complete Table XXVIII and then repeat the experiment with the angle of the board at about 35°.

Angle	*E + f*	*E – f*	*Avg. E*	*Plane*		*Weight (R) Roller or Car*	*Work out R x H*
				Length	*Height*		
25°							
35°							

Angle	*Work in E x L*	*Mechanical Advantage*	
		R/E	*L/H*
25°			
35°			

TABLE XXVIII

Questions and Problems:

1. The mechanical advantage (increases, decreases) .... as the angle of the inclined plane increases.
2. The work done in lifting the load on an inclined plane is (greater than, less than, equal to) .... the work done in lifting the load vertically.
3. Friction is a (help, hindrance) .... when an object is being taken up an inclined plane, but is a .... when it is being moved down the plane.
4. How does a wedge resemble an inclined plane? ....

....

5. A boy weighing 148 lbs. climbs a stairway $11\frac{3}{4}$ feet long and $8\frac{1}{2}$ feet high. How much work does he do? What is the M.A. of the stairway?

6. A hill on a highway has a 3% grade. What does this mean? ....

....

7. Does it take less effort to lift a heavy weight with a long, thin wedge or a short, thick wedge? Explain your answer. ....

....

8. A car, operating on an inclined track, is used to move freight from a river steamer to the freight warehouse. The track is 500 feet long and the floor of the warehouse is 60 feet above the river level. How much force is needed to draw the car, weighing $2\frac{1}{2}$ tons when loaded, up the incline, if its efficiency is 78%?

9. What is the "law of the inclined plane"? ....

....

10. How much force is needed to drive a 4 ton truck (when loaded) up a 3% grade. The efficiency is 75%.

11. A 2700 lb. auto is towed up a ramp 120 feet long. The pull on the tow rope is 340 lbs. What is the distance between floors if the efficiency is 90%?

12. How great a force will be required to hold a weight of 300 lbs. on an inclined plane 12 feet long and 3.5 feet high?

13. *a)* What is the M. A. of an inclined plane 20 feet long and 2 feet high? 4 feet high? 5 feet high? 8 feet high?

b) How much resistance could be held on each of these planes by a force of 60 pounds pulling parallel to the plane?

THE SCREW JACK

Purpose:

To determine the efficiency and mechanical advantage of the screw jack.

Tools and Materials:

Screw jack (1 ton)
Spring balance
Special 7 foot lever bar (See Fig. 103)
Heavy weight
Yard or meter stick

Procedure:

After determining the weight and center of gravity of the lever bar, set up the screw jack and lever as shown in Fig. 103, being sure that the

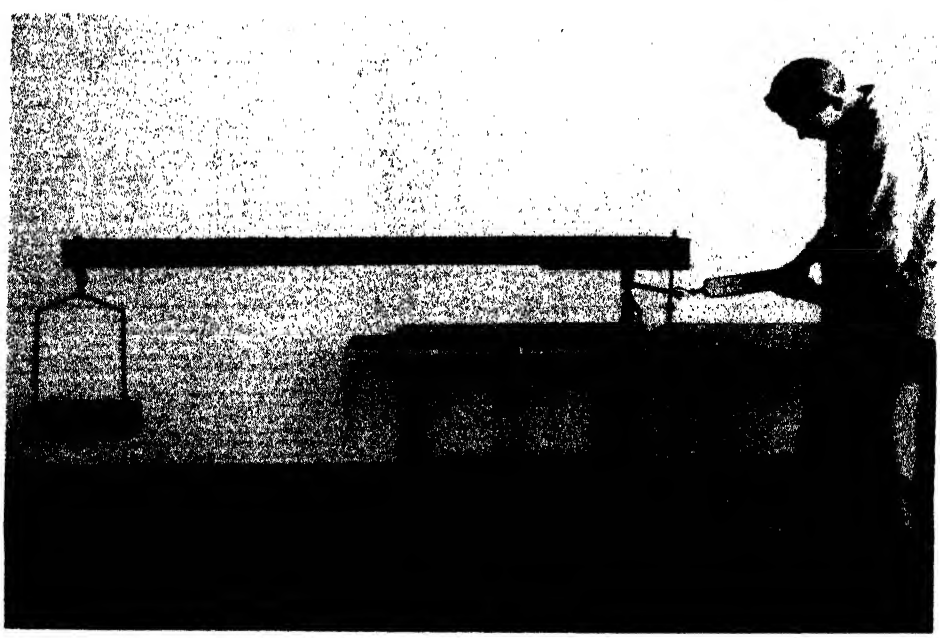


FIG. 103. FINDING THE EFFICIENCY OF A SCREW JACK.

lever is securely clamped in place. The beam should be kept horizontal when in use. Place the jack near the fulcrum and suspend a 50 pound weight on the hook at the opposite end of the bar. This will put a large weight on the screw jack.

Turn the jack handle by means of a spring balance and make the following measurements: *a)* balance reading, *b)* length of jack handle from center of screw to the point of contact with the spring balance hook, *c)* the pitch of the screw, *d)* the distance from the fulcrum to center of screw jack, *e)* distance from fulcrum to hook holding the weight. Record the measurements and weights in Fig. 104 and calculate the total load on the screw jack.

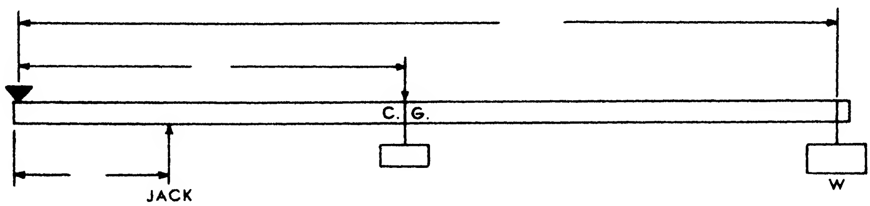


FIG. 104. DIAGRAM OF SCREW JACK LEVER PROBLEM.

What class of levers is illustrated by this diagram? ....

Assuming that the load is raised one foot, compute the amount of work done (output). Compute the circumference of the circle through which the effort acts; this, divided by the pitch of the screw will give the mechanical advantage (or velocity ratio). The input is found by multiplying the effort by the M. A. Complete Table XXIX.

Effort	*Total Load*	*Effort distance* $2\pi r$	*Pitch*	*M. A.*	*Output*	*Input*	*Efficiency*

TABLE XXIX

Questions and Problems:

1. Why are screws, used for fastening in wood, sometimes rubbed on a cake of soap before driving them? ....
2. What is the "principle of work"? ....

   ....
3. What is the "efficiency" of a machine? ....

   ....
4. The screw of a bench vise has $\frac{1}{4}''$ pitch. A force of 25 lbs. is applied on the lever bar 12″ from the center of the screw. If the vise is 35% efficient, what is the total force exerted on a piece of steel held between the jaws.?

5. With a screw jack having $\frac{1}{4}''$ pitch and a jack handle 18″ long it is necessary to use 15 lbs. to raise a weight of 2500 lbs. What part of the force is lost because of friction?

6. What is meant by the term "pitch of a screw"? ....

....

7. A plumber cut 10 threads to an inch (10 TPI) on a pipe, using a stock and die having an effective handle of 18″. What is the greatest M. A. obtainable with this outfit?

8. A mechanic exerts 20 lbs. effort in screwing a nut down on a $\frac{7}{16}''$ bolt, 14 TPI. If he uses an effective wrench handle of 8″, what force is being exerted by the nut?

9. If, in problem 8, the mechanic was using 60 lbs. effort and a 12″ effective handle, what force would the nut exert if the bolt was $\frac{7}{8}''$, 9 TPI?

TOOLS WHICH APPLY THE INCLINED PLANE PRINCIPLE

FILES

Files, in some form, are used in the maintenance or production of practically every form of commodity. There are many styles and types of files, but they all work on the principle of the wedge or inclined plane. In 1923 the Bureau of Standards established and named 23 basic types of files. Before this, endless unstandardized varieties existed. There are three standards of coarseness of cut in American Pattern Files, namely the Bastard cut (with the least number of teeth per inch), Second cut (with more teeth per inch than the Bastard cut) and Smooth cut (with the greatest number of teeth per inch). They are also referred to as coarse, medium and fine. (The term Bastard, as applied to a file, denotes the coarseness of cut only). Mill files are single cut while Flat files are double cut. Fig. 105 shows the Standard Tooth Cuts used on files.

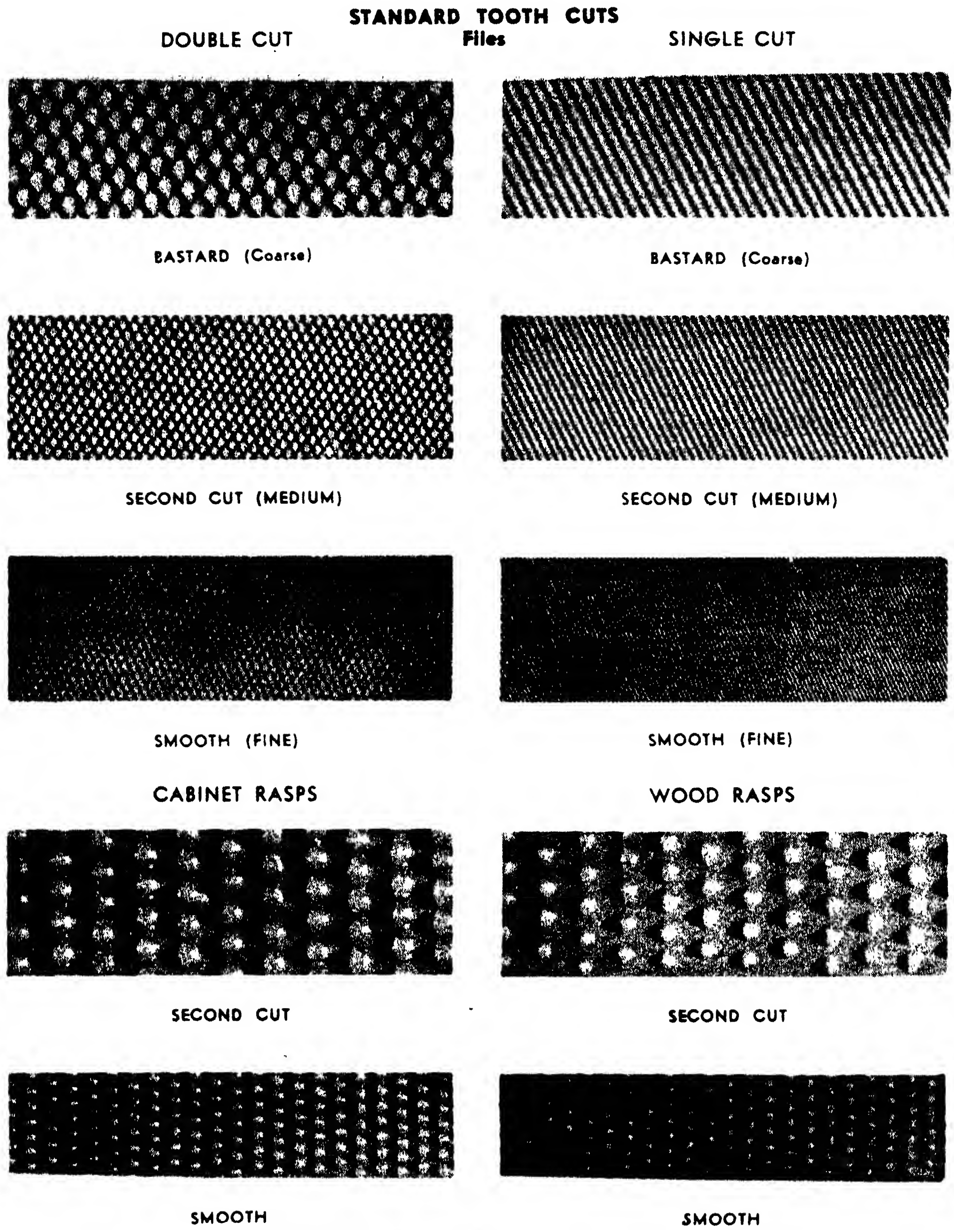


FIG. 105. TYPES OF FILES.

A few rules for the correct use of a file are as follows:

1. Since the "business end" of a file is its cutting edge, care should be exercised in protecting this edge. Files should not be thrown carelessly upon benches or into bench drawers to be knocked against other tools. Files, when not in use, should be kept in racks or in a specially partitioned drawer.

2. Files should be kept clean by brushing with a file card or brush. A dirty file is a dull file.

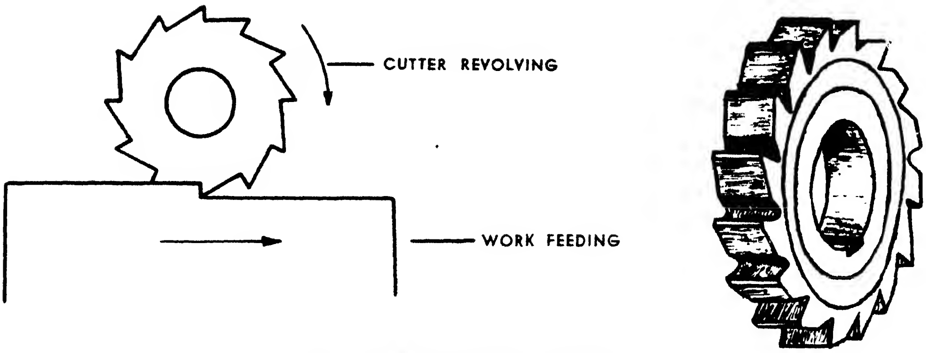


FIG. 106A. MILLING CUTTER.

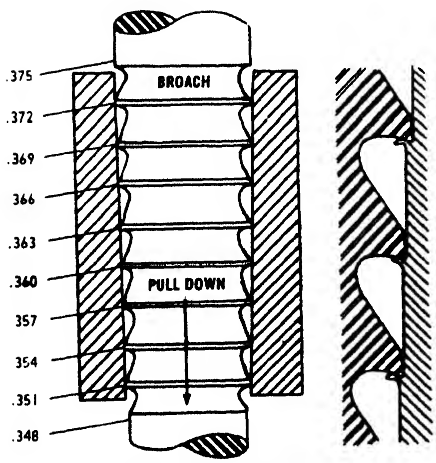


FIG. 106B. BROACH.

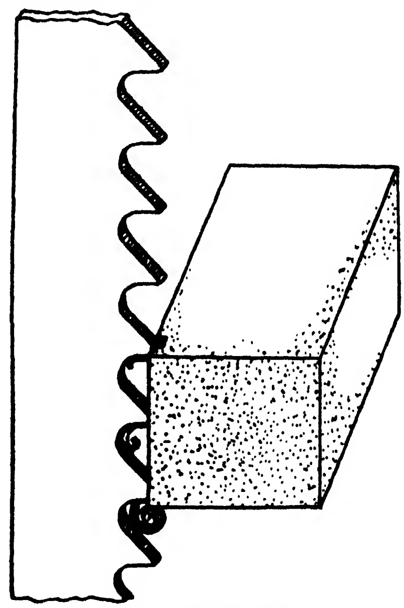


FIG. 107A. HACK SAW.

3. Filling the teeth of a file with chalk will prevent the chips from clogging the teeth and lessen the possibility of scratching the work being filed.

4. Never "ride" a file on the back stroke. A file tooth has a definite shape and is formed to cut when stroked in the forward direction. Failure to relieve the pressure on the back stroke, means definite injury to the file tooth.

OTHER TOOLS

Milling cutters, saws, lathe tool-bits, broaches, and drills all utilize the inclined plane principle in their cutting edge. This principle is clearly shown in Figs. 106, 107A, 108, 109, and 110. Note that the shank of some twist drills is tapered to aid in holding the drill firmly in the chuck. A taper is, of course, an inclined plane.

HACK SAWS

Hack saws operated by hand are widely used, therefore a few suggestions concerning their selection and use will be of value.

Hack saw blades are made of high grade tool steel, hardened and tempered or of special alloy steels for cutting harder metals. There are two types: the all-hard blades are hardened throughout, while only the

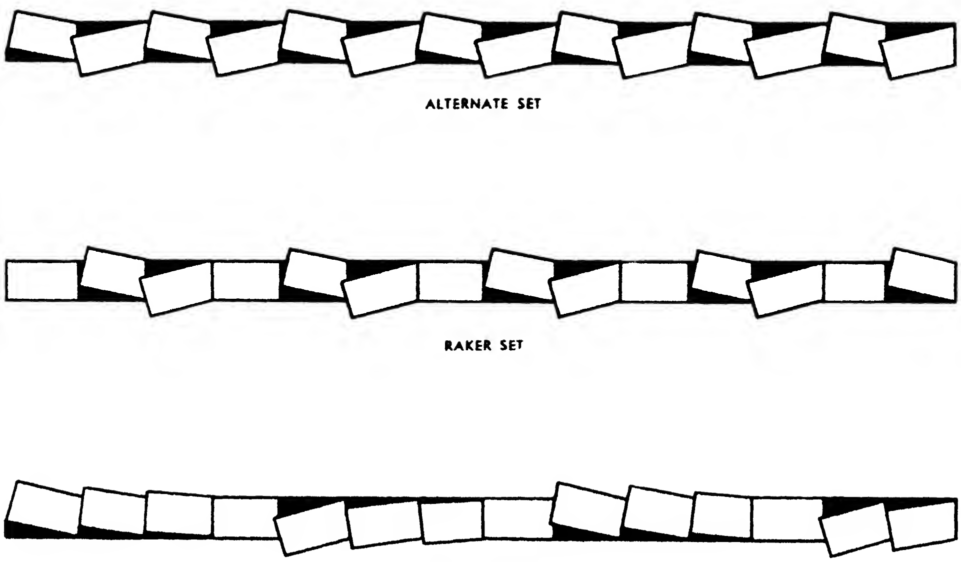


FIG. 107B. THREE METHODS OF "SETTING" SAWS.

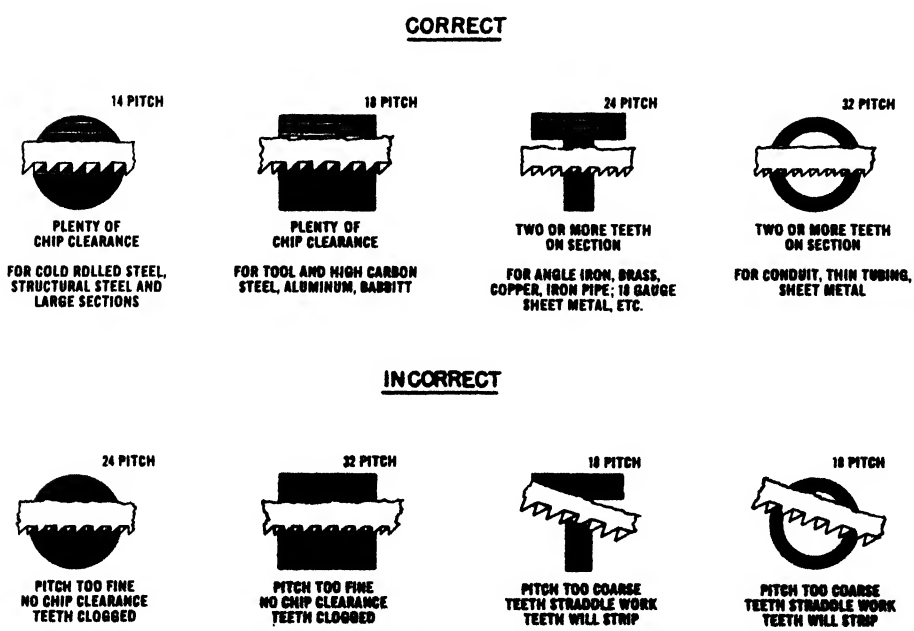


FIG. 107C. SELECTING HACK SAW BLADES.

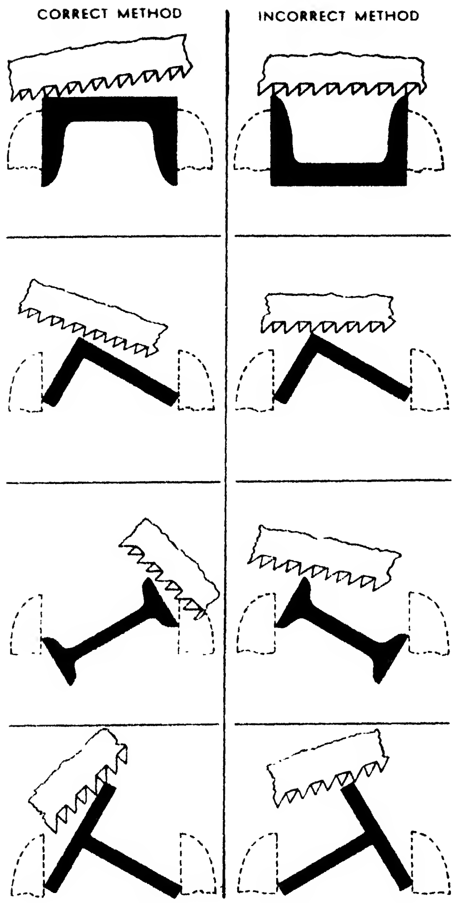


FIG. 107D. STARTING A HACK SAW CUT.

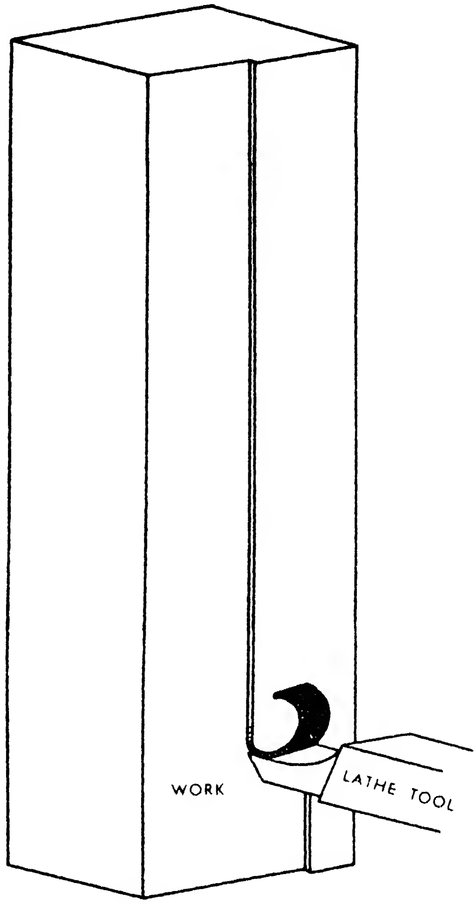


FIG. 108. LATHE TOOL.

teeth of the flexible blades are hardened. The usual range of sizes is from $\frac{7}{16}''$ to $\frac{9}{16}''$ wide; 8″ to 16″ long, with a pitch of 14 to 32 teeth per inch. To provide clearance, all hack saw blades are "set." Three kinds of "set" are commonly found. Namely, raker set, alternate set and undulated set. See Fig. 107B. Alternate set means that alternate teeth are bent slightly sidewise in opposite directions; on a raker set every third tooth remains straight; and the other two are set alternately; on an undulated set blade, short sections of teeth are bent in opposite directions.

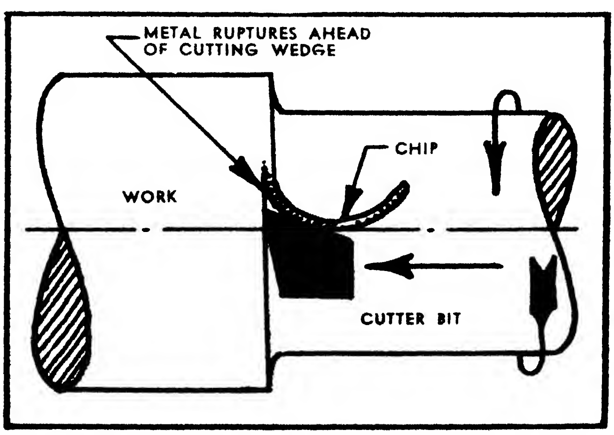


FIG. 109. CUTTING ACTION OF LATHE CUTTER BIT.

The all-hard blade is best for sawing brass, tool steel, cast iron and stock of heavy cross section. The flexible blade is best for sawing hollow shapes and metals of light cross section such as channel iron, tubing, tin, copper, aluminum and babbitt. The correct selection of pitch is shown in Fig. 107C.

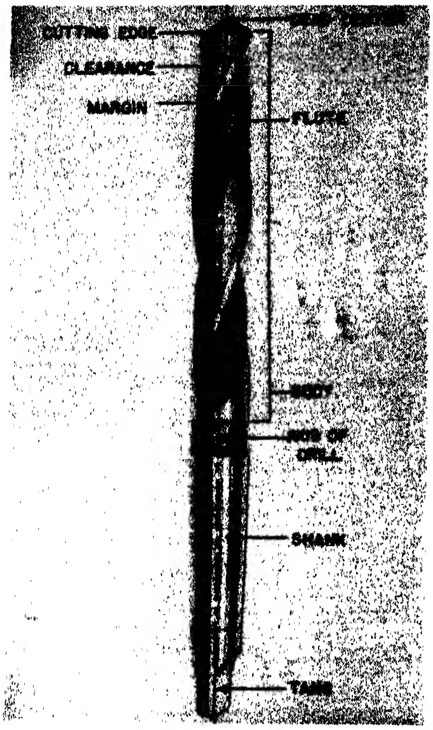


FIG. 110. TWIST DRILL.

The hack saw should be held vertically and moved forward with a light stroke. At the end of the stroke, relieve the pressure and draw the blade straight back. After the first few strokes, make each stroke as long as possible without striking the saw frame against the work. Do not press down on the saw on the return stroke. Keep the saw in the same plane throughout the cut in order to prevent cramping and breaking the blade. The most effective cutting speed is 50 to 60 strokes per minute. When the work is nearly cut through, raise the saw slightly to prevent the teeth from catching. Be sure the work being cut is gripped tightly in a vise. Fig. 107D shows right and wrong positions for clamping various shapes when starting a hack saw cut.

GEARS AND GEARING

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Introduction:

Gears are another application of the wheel and axle (or lever) principle. They are used to *transmit rotation* from one shaft to another *without slippage.* The shafts may run parallel or may operate at various angles to each other. Since gears operate under so many conditions and for such widely different purposes, many types and sizes are in daily use. A complete understanding of all phases of gearing requires a great deal of tech-

nical information and ability. The purpose of this discussion is to give information which will be of value when using gears.

There are many tooth curves which could be used on gear wheels to obtain uniform motion. However, only two have any extensive use. These are the *cycloid,* which was first suggested by the Danish Astronomer Olaf Roemer about the year 1674, and the *involute,* which was first put into practical use by Robert Willis, professor at the University of Cambridge, about the year 1700. The words *cycloid* and *involute* are mathematical terms used to describe certain types of curved lines.

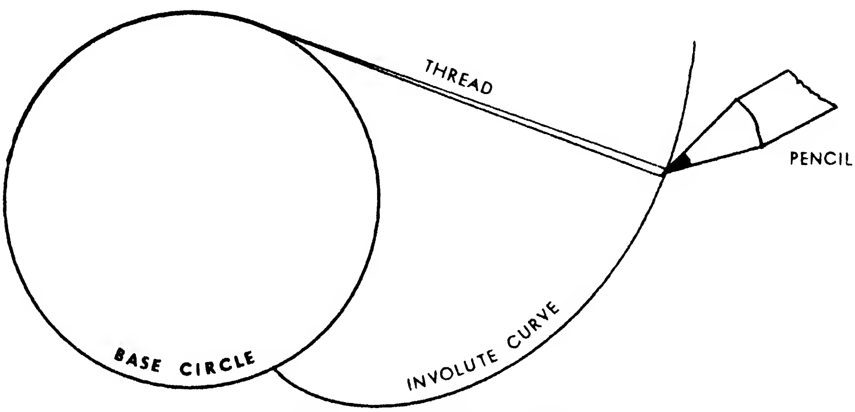

FIG. 111. INVOLUTE CURVE.

INVOLUTE CURVE

Shown in Fig. 111 is a simple method for generating (drawing) an involute curve. A circle, representing the base circle of a gear, is cut out of heavy cardboard. A thread is fastened to the edge of the cardboard and is tightly wrapped part of the way around it. A sharpened pencil, placed in the looped end of the thread and pressed against the paper will trace the involute curve as the thread is unwound from the edge of the cardboard circle. The diameter of the base circle will determine the shape of the involute curve.

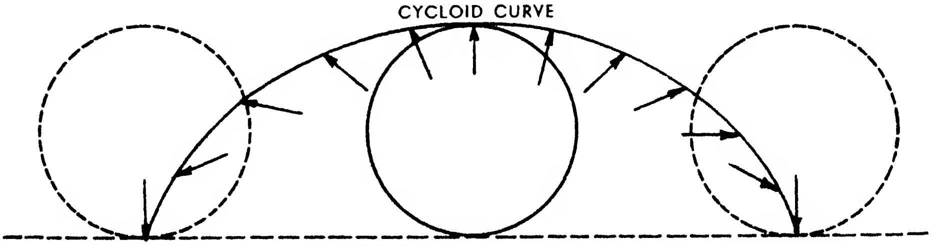

FIG. 112. INVOLUTE GEAR TOOTH.

Fig. 112 shows an involute gear tooth. Involute gears have the advantage that when two shafts are not at exact center distance, the mating of the teeth is still satisfactory. Because of this and the fact that the

teeth on high speed gears are now machine cut, the involute tooth form has replaced the cycloidal tooth.

CYCLOID CURVE

Shown in Fig. 113 is the generation of a cycloid curve. The arrow point on the disk, traces this curved line when the disk is rolled along a straight line.

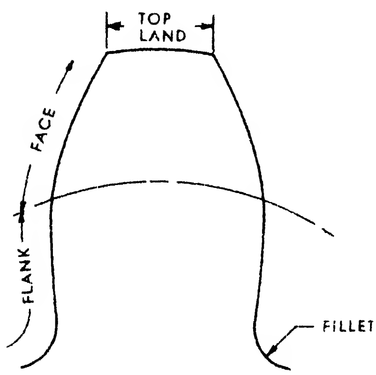

FIG. 113. CYCLOID CURVE.

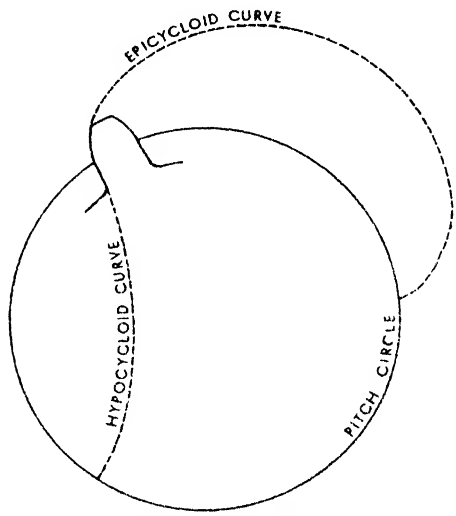

FIG. 114. GENERATING A CYCLOID GEAR TOOTH.

EPICYCLOID AND HYPOCYCLOID CURVES

Before the development of such machines as the automobile and the airplane, most gear wheels were made by casting. These gears used the cycloid tooth Fig. 114 and were usually of one inch circular pitch or more. In the cycloid tooth the "face" (the part outside the pitch circle) is an *epicycloid* curve while the "flank" (the part inside the pitch circle) is a *hypocycloid* curve.. (See Figs. 115 and 116.)

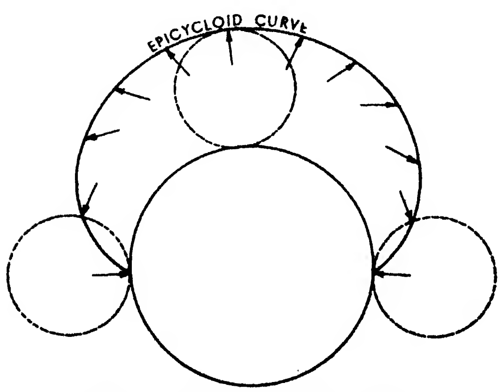

FIG. 115. EPI-CYCLOID CURVE.

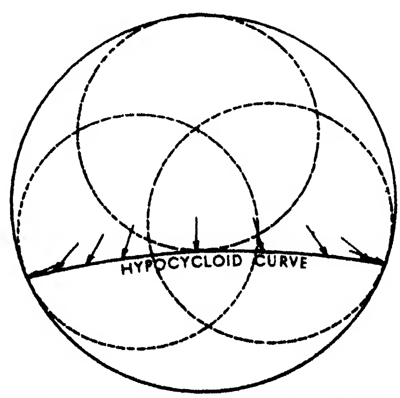

FIG. 116. HYPO-CYCLOID CURVE.

An *epicycloid curve* is generated when one circle rolls upon another circle. (Fig. 115.)

A *hypocycloid curve* is generated when a circle rolls within another circle. (Fig. 116.)

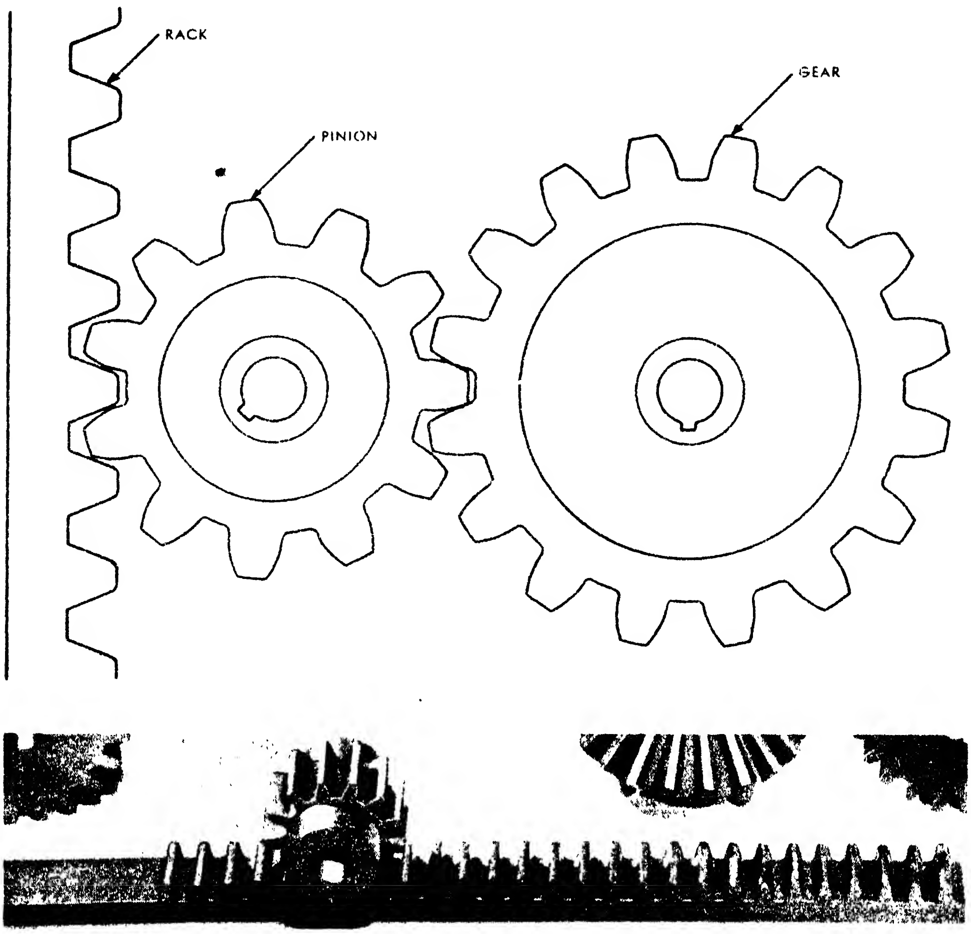

FIG. 117A. INVOLUTE RACK AND PINION GEARS. (Courtesy, Link-Belt Co.)

Fig. 117A shows a spur gear and a rack having the involute form of tooth. This is the most commonly used type of gear tooth. Spur gears are used to connect shafts which run parallel to each other, the teeth being straight and parallel to the axes of the gears. When one of the gears is much smaller than the other it is known as a "pinion" gear.

Two spur gears in action are comparable to two corresponding plain rollers whose surfaces are in contact, these surfaces representing the pitch circles of the gears.

Fig. 118 shows the NOTATION used in describing the parts of a spur gear.

FIG. 117B. RAWHIDE AND BAKELITE SPUR GEARS. (Courtesy, W. A. Jones Foundry and Machine Co.)

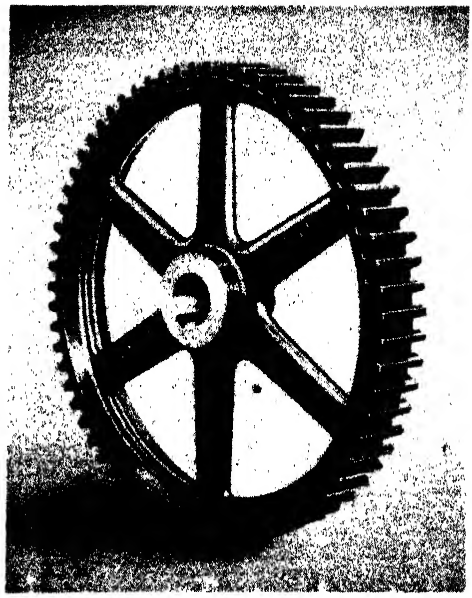

FIG. 117C. SPUR GEAR. (Courtesy W. A. Jones Foundry and Machine Co.)

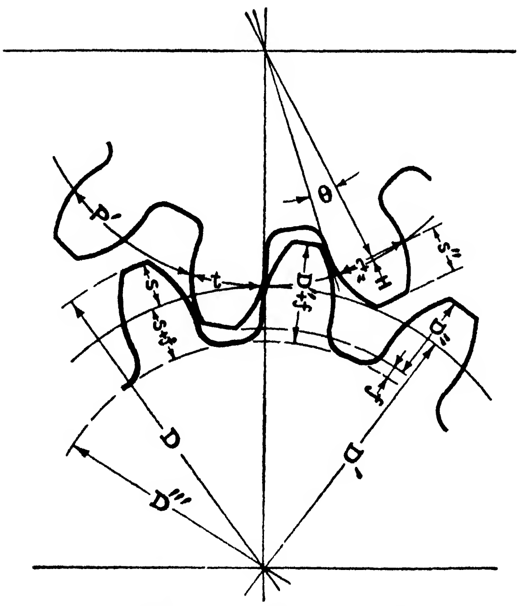

FIG. 118. GEAR NOTATION. (Courtesy, Brown & Sharpe Mfg. Co.)

P — diametral pitch or the number of teeth to one inch of pitch diameter.
N — number of teeth
D′ — pitch diameter
s — addendum
f — clearance at bottom of tooth
s + f — dedendum
t — thickness of tooth on pitch line
t″ — chordal thickness of tooth
D″ — working depth of tooth
D″ + f — whole depth of tooth
D — outside diameter
D‴ — bottom diameter
P′ — circular pitch
H — height of arc
s″ — distance from chord to top of tooth
Θ — ½the angle subtended by circular pitch

Fig. 119 gives a better idea of an involute rack. A rack is a straight bar with teeth cut in it, engaging the teeth of a spur gear. When the gear is revolved, the rack is moved in a straight line.

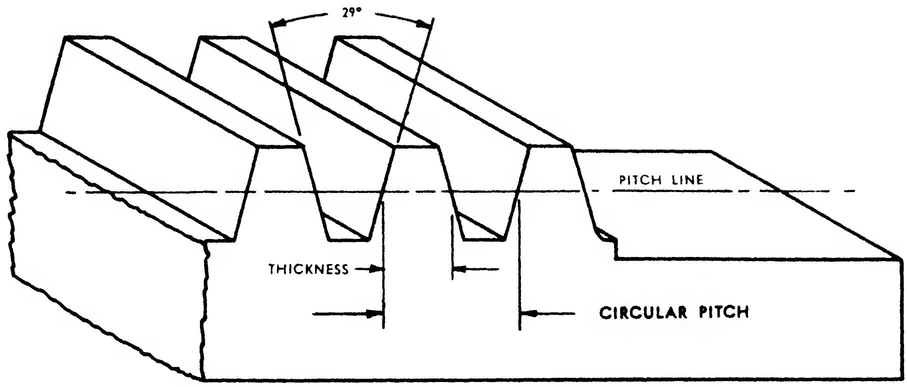

FIG. 119. INVOLUTE RACK.

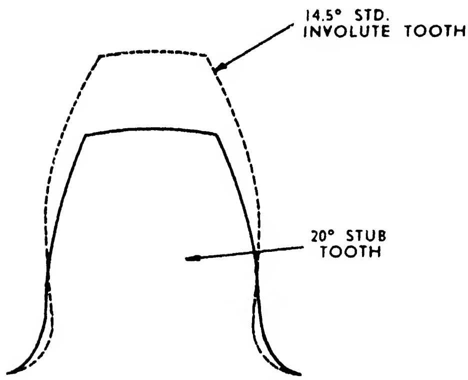

FIG. 120. STUB AND INVOLUTE TOOTH COMPARED.

Fig. 120 shows a comparison of the teeth commonly used on spur gears, the $14\frac{1}{2}°$ standard involute and the 20° Stub tooth. The stub will be seen to be a shortened or cut off tooth. It has greater strength than the $14\frac{1}{2}°$ involute gear tooth and is used in power transmissions requiring greater tooth stability. Fig. 121 illustrates an internal gear. This type of gear has several advantages over the external gear such as shorter center distances, greater strength, etc. A common use of this type of gear is found in the drive wheels of a lawn mower, or in the reduction gears of an airplane propeller.

An enlarged drawing, Fig. 122 shows to a better advantage the difference between tooth thickness on the pitch circle and chordal thickness (See definition of chord). Chordal thickness is the measurement obtained with a gear tooth caliper. Fig. 123.

Gearing Terms and Their Meaning:

PITCH POINT.—The point of tangency of the two pitch circles of a pair of gears (t' in Fig. 118).

TANGENT.—Two circles, or a line and a circle, which barely touch each other without intersecting.

PITCH CIRCLE.—A circle whose radius is the distance from the gear axis to the pitch point. (See Fig. 118.)

PITCH DIAMETER.—The diameter of the pitch circle (D' in Fig. 118).

ROOT OR BOTTOM DIAMETER.—(D''' in Fig. 118.) The diameter of the root circle.

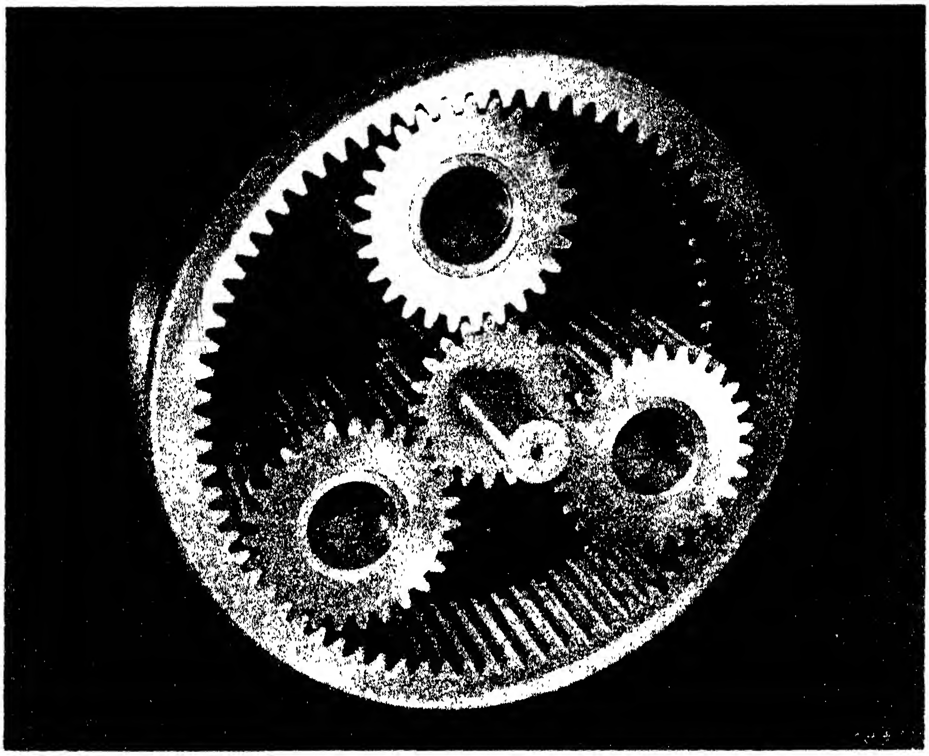

FIG. 121. AN INTERNAL GEAR. (Courtesy Gear Grinding Machine Co.)

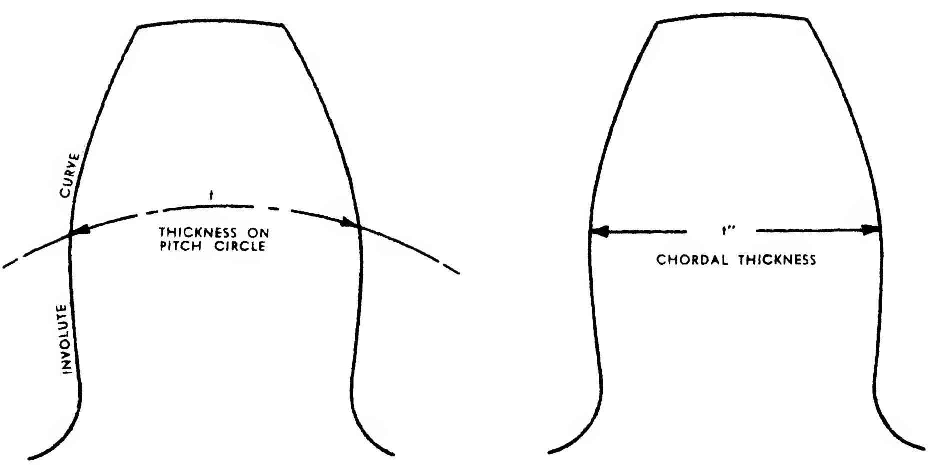

FIG. 122. CHORDAL AND PITCH CIRCLE THICKNESS.

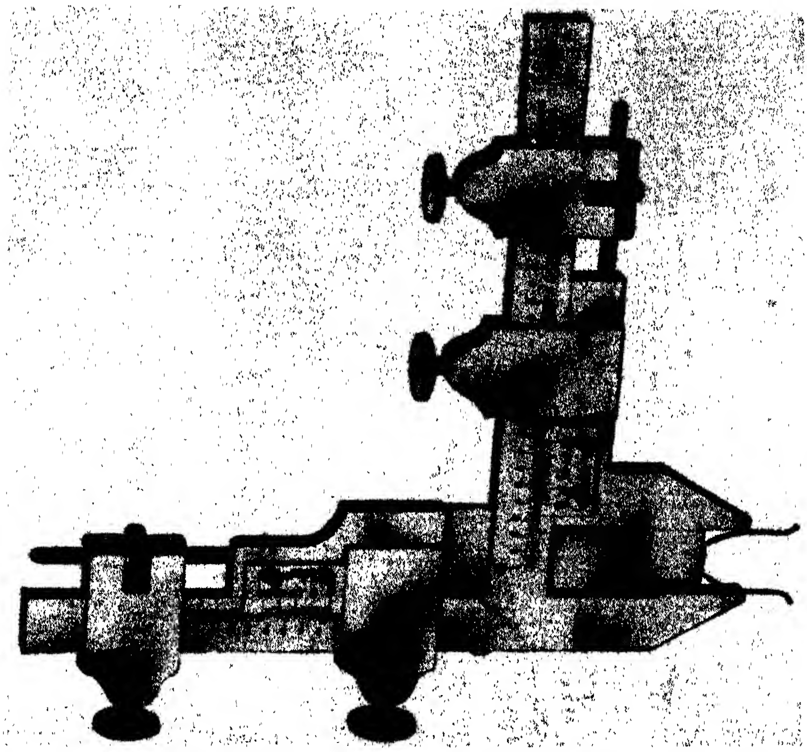

FIG. 123. GEAR TOOTH VERNIER. (Courtesy, Brown & Sharpe Mfg. Co.)

Root Circle.—A circle joining the bottoms of the tooth spaces.

Outside Diameter.—(D in Fig. 118.) The diameter of a circle joining the top lands of the gear teeth. (Top land is the top flat surface of a tooth).

Circular Pitch.—The distance on the pitch circle from the edge of one tooth to the corresponding edge of the next tooth (P′ in Fig. 118).

Diametral Pitch.—The number of gear teeth to one inch of pitch diameter.

Face of Tooth.—The surface of the tooth which is between the pitch circle and the top of the tooth (see Fig. 118).

Flank of Tooth.—The surface of the tooth which is between the pitch circle and the bottom, including the fillet. (See Fig. 118.)

Fillet.—The rounded corner at the bottom of the tooth where the flank runs out into the tooth space. (See Fig. 118.)

Addendum.—The height of the tooth above the pitch line (s in Fig. 118).

Dedendum.—The depth of the tooth space below the pitch circle (s + f in Fig. 118).

Gear teeth are designated by *diametral pitch numbers.* Fig. 124 shows a comparison of the actual sizes of involute teeth.

A 20 P gear means 20 teeth to each inch of diametral pitch. If the 20 P gear has a 2.5″ pitch diameter, it will have 50 teeth. It is understood that the diametral pitch of a gear is to be used when pitch is mentioned unless circular pitch is definitely specified.

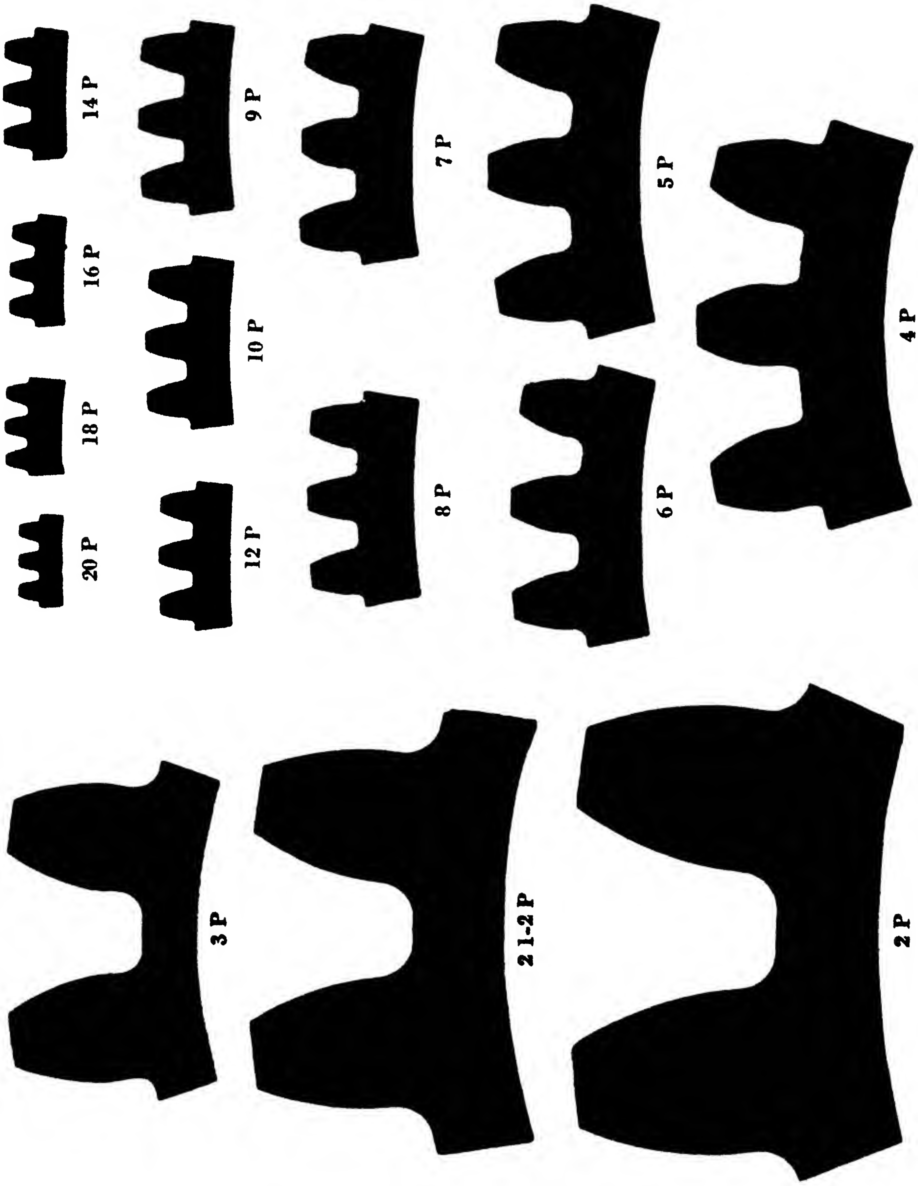

FIG. 124. COMPARATIVE SIZES OF INVOLUTE GEAR TEETH.
(Courtesy, Brown Sharpe Mfg. Co.)

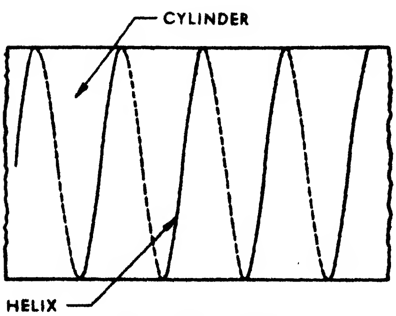

FIG. 125. HELIX.

Fig. 125 shows a helix. When a cylinder is made to revolve and move uniformly forward at the same time, a piece of chalk pressed against it will trace a curved line which is known as a helix. The thread of a screw is a helix.

Fig. 126 shows a helical gear and pinion. Gears with curved teeth are

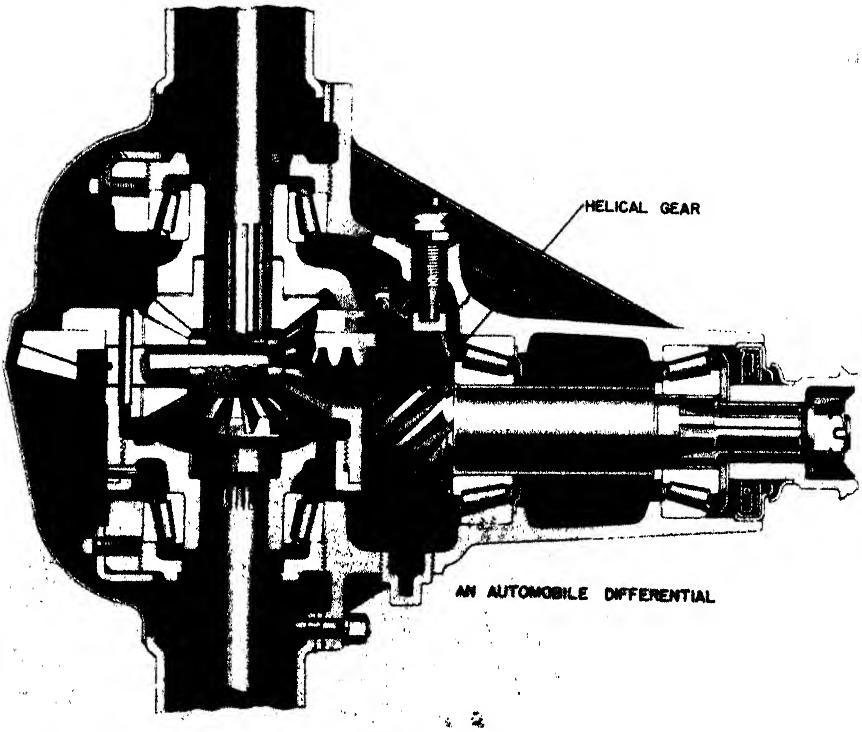

FIG. 126. HELICAL GEAR AND PINION. (Courtesy, Chrysler Corporation.)

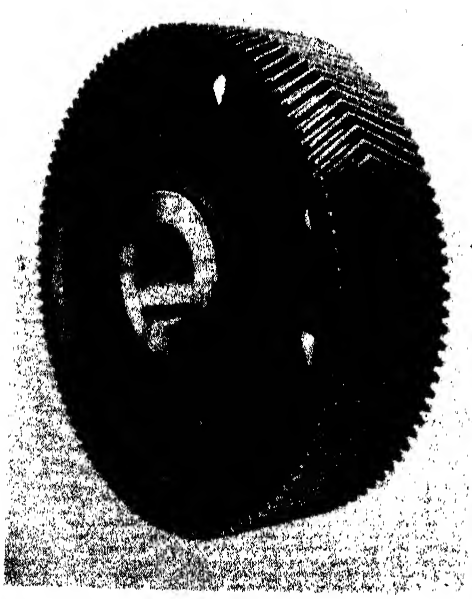

FIG. 127A. HERRINGBONE GEAR (Courtesy, W. A. Jones Foundry and Machine Co.)

FIG. 127B. HERRINGBONE SPEED REDUCER (Courtesy, W. A. Jones Foundry and Machine Co.)

known as helical gears. They may be used to drive shafts which are parallel or at right angles to each other. Gears of this type are smoother running and make less noise than spur gears. Since the contact between the teeth of helical gears is a sliding action rather than a rolling action as in the case of spur gears, helical gears should run in a bath of oil.

Herringbone gears (Fig. 127) have two sets of helical teeth opposing each other. Such gears have smooth, continuous action and run silently. Because of the shape of these gears they take up any end thrust that might be present, thus eliminating the need of thrust bearings. There are two types of herringbone gears, those with "matched" teeth (Fig. 127) and those having staggered teeth.

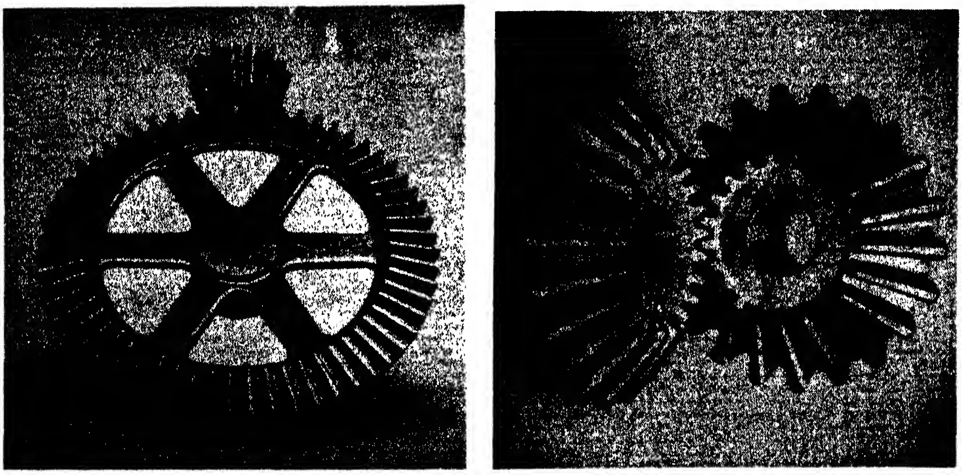

FIG. 128. BEVEL OR MITER GEARS. (Courtesy W. A. Jones Foundry and Machine Co.)

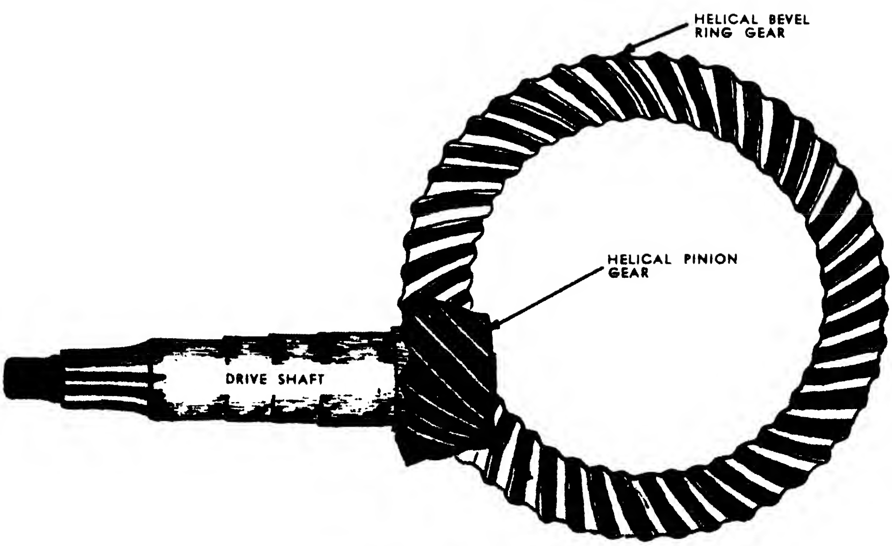

FIG. 129. HYPOID GEAR.

Bevel gears (Fig. 128) are used to connect shafts at right angles to each other and which would meet if they were prolonged. The axes of the shafts are usually at right angles and in such a case beveled gears are known as "miter" gears. Bevel gears have straight teeth such as found in spur gears. A helical bevel gear is shown in Fig. 129. This gear is found in the hypoid drive of one of the better makes of automobiles. Straight bevel spider gears will also be noticed in the differential of this drawing.

Hypoid gears are used in automobile drives in order to lower the driving shaft and thus eliminate the hump in the floor, making it possible to lower the center of gravity of the car. Hypoid gears differ from the ordinary type of bevel gears in that the drive shaft would not meet the axis of the rear axle if it were prolonged.

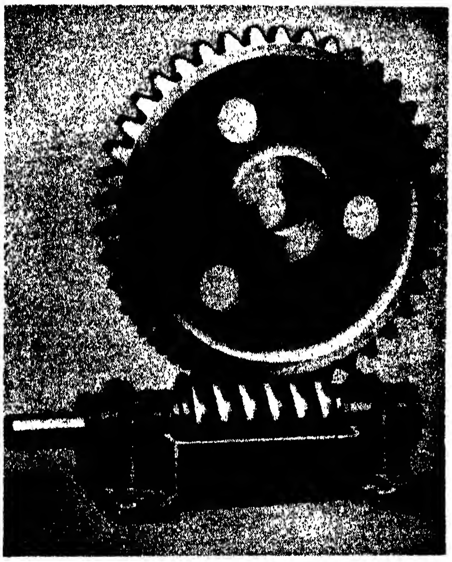

FIG. 130. WORM GEAR. (Courtesy, W. A. Jones Foundry and Machine Co.)

Worm gears (Fig. 130) are used to transmit rotary motion from one shaft to another when the shafts are not parallel. Such shafts are usually operating at right angles to each other. Worm gears are exceedingly smooth in action and bring about a great reduction in speed of rotation. The diagram shows the two units used in this type of gearing, the *worm gear* and the *worm*. The worm resembles a screw thread.

GEAR TRAINS

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SIMPLE GEARING

In a simple train of gears, Fig. 131, an "idler" or "intermediate" gear is used to connect the driving gear with the driven gear. The number of teeth in the idler or the number of idler gears used have no effect on the speed of the driven gear.

COMPOUND GEARING

A compound gear consists of two or more gear wheels mounted on the

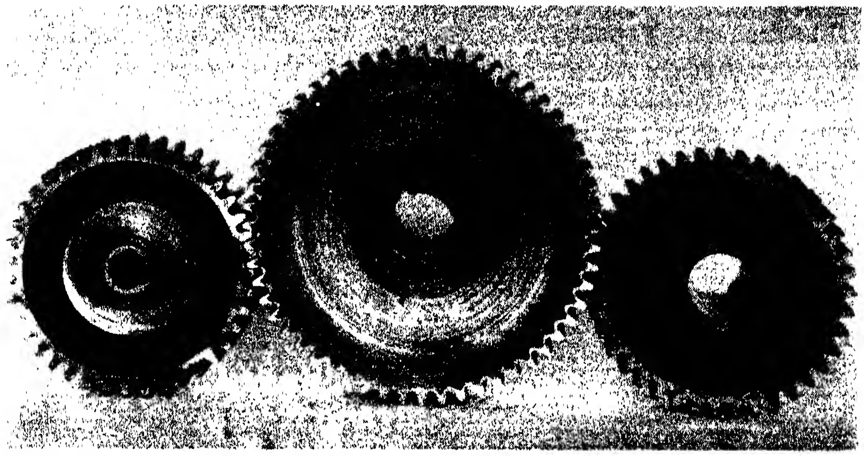

FIG. 131. SIMPLE GEARING.

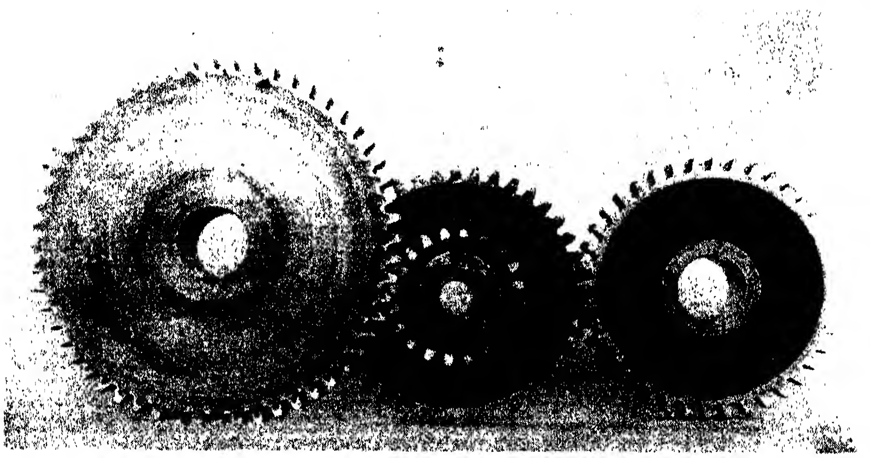

FIG. 132A. COMPOUND GEARING.

same shaft in such a way that they both rotate at the same speed in the same direction (see Fig. 132A). From this it will be seen that a compound gear is a modification of the "wheel and axle."

IDLER GEARS

Purpose:

To determine the effect of idler gears on speed ratios and the direction of rotation of gears.

Materials:

Four geared wheels having the same pitch; board or metal plate arranged for mounting the gears in different combinations.

Procedure:

Arrange the wheels in the combinations shown in Fig. 133A.

Arrangement (a)

Select one wheel as a driver and one to serve as the follower through-

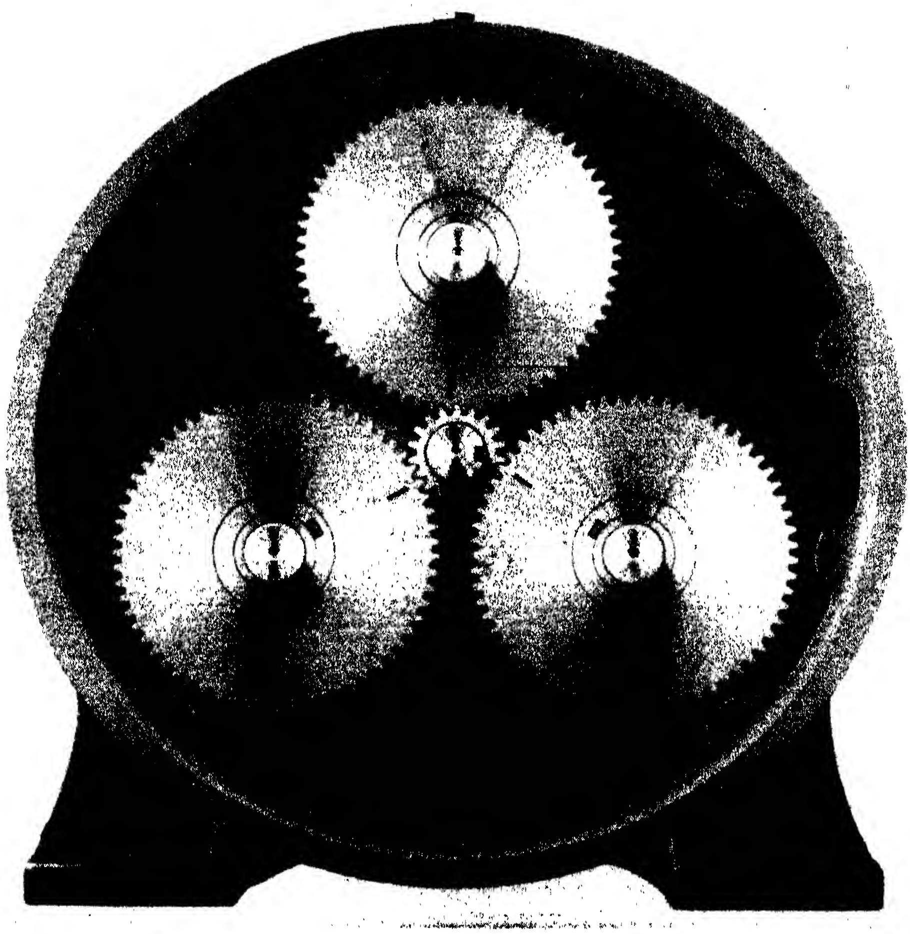

FIG. 132B. SPUR GEAR REDUCER. (Courtesy, W. A. Jones Foundry and Machine Co.)

out this entire experiment. Place marks on these wheels with a piece of chalk so that the rotation of each wheel can be easily followed. Placing these marked teeth together at the start, rotate the driving gear (B) until the driven gear (A) has made one complete revolution.

1. How man turns did the driver (B) make in moving the driven gear (A) through one complete revolution? ....

Place an arrow on the driven gear (A) (Fig. 133A) to indicate the direction in which it turns.

2. The driven gear (A) turned in the (same, opposite) .... direction as the driver (B).

Arrangement (b)

Place an idler gear between the gears A and B. Repeat the tests per-

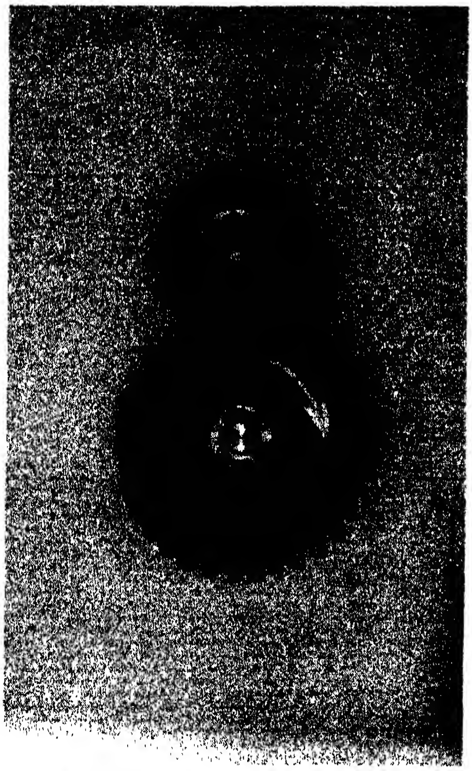

FIG. 133A. SPUR GEARS - NO IDLERS

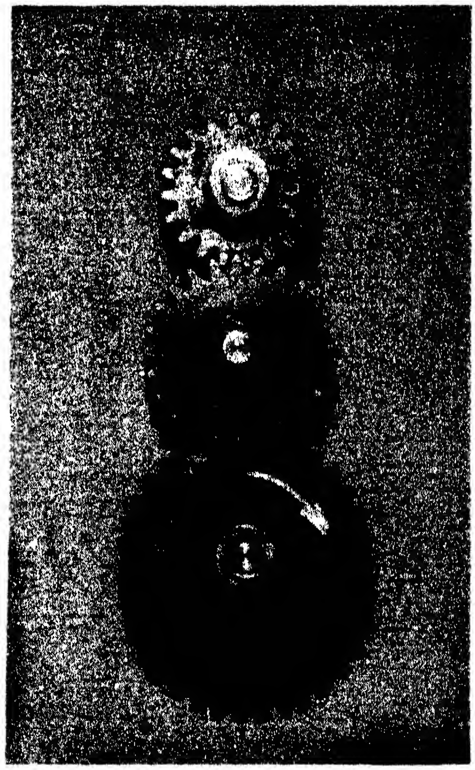

FIG. 133B. SPUR GEARS - ONE IDLER

formed in arrangement (a). Place arrows on Fig. 133B to indicate the direction the gear wheels turn.

3. The idler gear caused the driver gear (B) to be turned (more, less, the same number of) .... turns, when the driven gear (A) made one complete revolution, as compared with arrangement (a).

4. The direction the driven gear (A) revolves is (the same, reversed) ....when the idler gear is used.

Note: This experiment illustrates how an automobile is made to reverse its direction. A small idler gear is used between the countershaft gear and the drive gear. (See Fig. 141.)

Arrangement (c)

Place two idler gears between the gears (A) and (B). Repeat the tests, marking the direction or rotation (Fig. 133C) with arrows.

5. (Choose the correct words.) An idler gear (does, does not) ....affect the speed ratio between the driver and driven gears (and, but) .... (does, does not) .... change their direction of rotation.

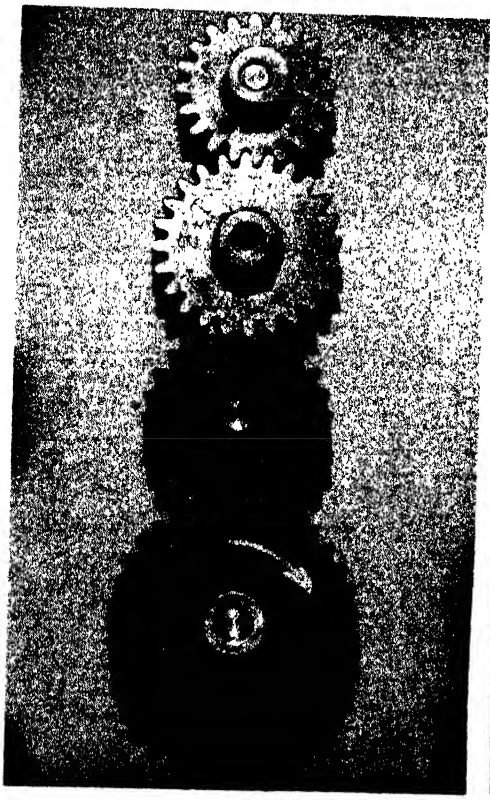

FIG. 133C. SPUR GEARS - TWO IDLERS.

FIG. 134. TRAIN OF GEARS.

COMPOUND AND WORM GEARS

Purpose:

1. To determine the speed ratio of a train of gears containing compound gears; also for worm gears.
2. To determine the mechanical advantage and efficiency of a train of gears.

Introduction:

Speeds of lathes and automobiles are controlled by gear trains. The steering gear and speedometer gears of an automobile are worm gears. The tests to be performed in this experiment are to show and explain the principles of gearing which make possible these uses.

Materials:

Gear train; worm gear; weights and cord.

Procedure:

Set up the train of gears as shown in Fig. 134. Place a weight R (500 g.) on the axle and adjust the effort E by adding weights until the resistance R moves upward at a uniform speed when the effort is given a start. Record as (E + f). Remove weights from E until R moves uniformly

downward, recording as (E − f) in Table XXX. Repeat the test, using 1000g.; 1500g.; 2000g.; and 2500g. as the resistance.

	Effort (E)			*Mechanical Advantage*	
	Downward	*Upward*	*Ave.*	*Actual*	*Ideal*
Load (R)	$E + f$	$E - f$	E	$R \div (E + f)$	$R \div E$ (Ave.)
500					
1000					
1500					
2000					
2500					

TABLE XXX

Mark one tooth on the driver gear (5) and the follower gear (2) with black paint or chalk so that the number of revolutions can be counted.

1. How many revolutions does gear 5 make for one revolution of gear 2? .... This is the gear ratio of this train of gears.
2. Give the wheel numbers which act as a "wheel" and "axle." Wheel .... Axle ....
3. Calculate the M. A. of this wheel and axle.

   Formula — M. A. = ...

4. Count the number of teeth on the gear wheels.

   Wheel No. 2 .... No. 3 .... No. 4 ....

   No. 5 .... Calculate the M. A. of the gear train.

   Formula — M. A. = ... × ....

5. Calculate the ideal M. A. of the entire machine (Fig. 134).
6. How does the answer to problem 5 compare with that in Table XXX?

   ....

   ....

In the space, Fig. 135 make a graph showing the relationship of the load to the effort and to the efficiency.

Set up the worm gear as shown in Fig. 136. Place a 2000g. load on the drum on the worm wheel. Place weights on the string attached to the drum on the worm in order to determine the effort needed to lift the 2000g.

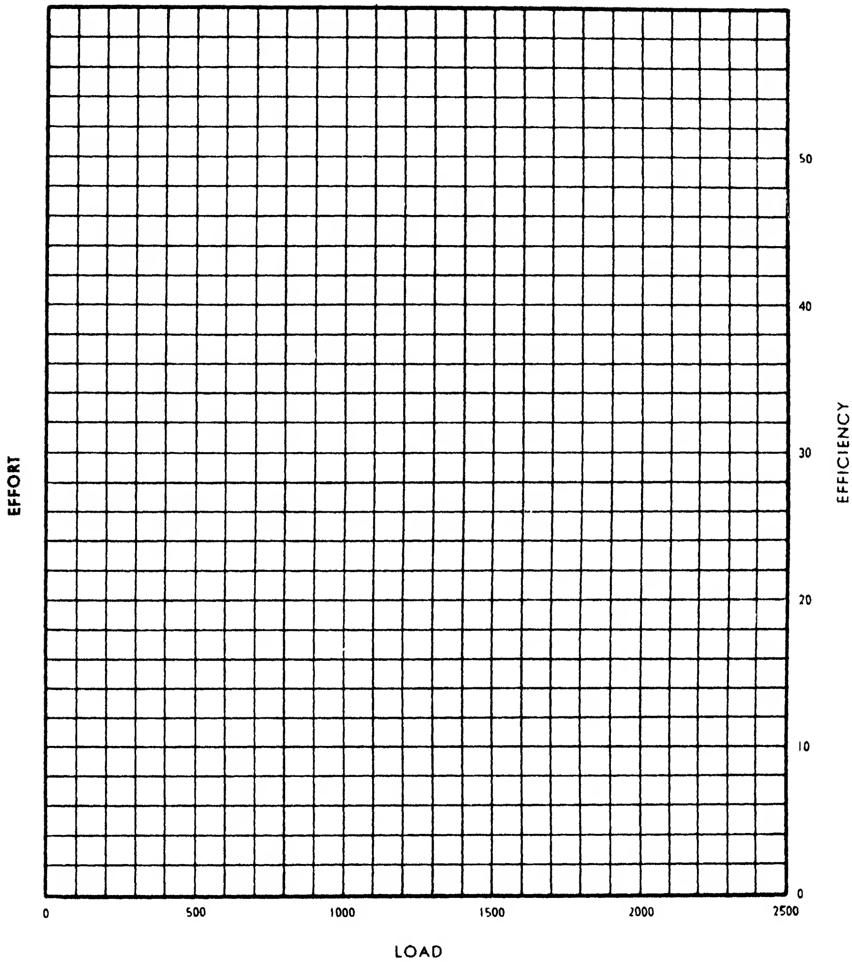

FIG. 135.

7. The effort needed is .... g.

8. The actual M. A. of the gear (R ÷ E) is ....

9. How many teeth does the worm gear have? ....

10. How many revolutions must the worm make to rotate the worm wheel one complete turn? .... Explain ....
....

11. Calculate the ideal M. A. of the machine, Fig. 136.

How does this result compare with the actual M. A. found in Prob-

lem 8? ....

Explain ....

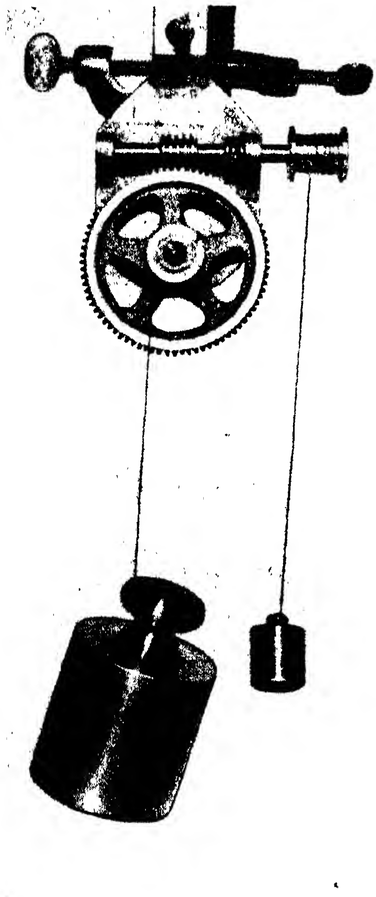

FIG. 136. WORM GEAR.

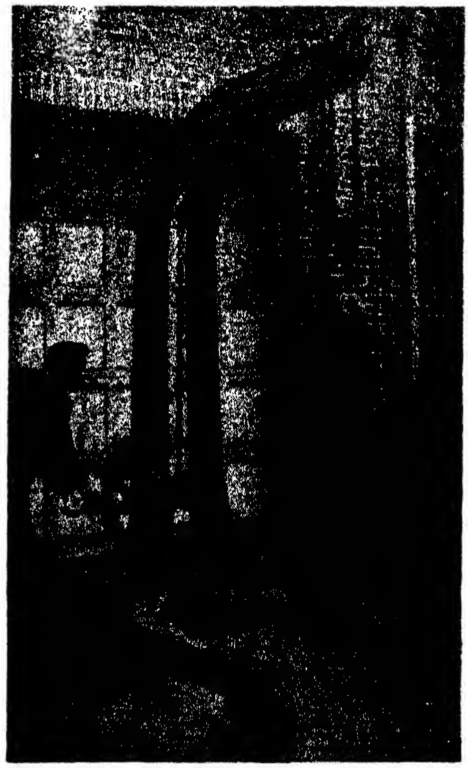

FIG. 137. PORTABLE CRANE.

Questions and Problems:

1. **The portable shop crane, Fig. 137 has a crank handle 11″ long and a steel drum 4″ in diameter. The drum gear has 68 teeth and the pinion gear has 14 teeth.**

   a) **Find the ideal M. A. of the crane.**

b) Calculate the gear ratio of the crane.

c) If the crane is 60% efficient, how much force will have to be exerted on the crank to lift a 1000 pound weight?

2. The winch, Fig. 138, has 74 teeth on the drum gear and 22 teeth on the pinion gear. The drum is 4″ in diameter and the crank handles are 12″ long. *a)* Find the ideal M. A. of the entire machine.

b) If 6 pounds effort is required on each crank to lift a 500 pound weight, what is the efficiency of the winch?

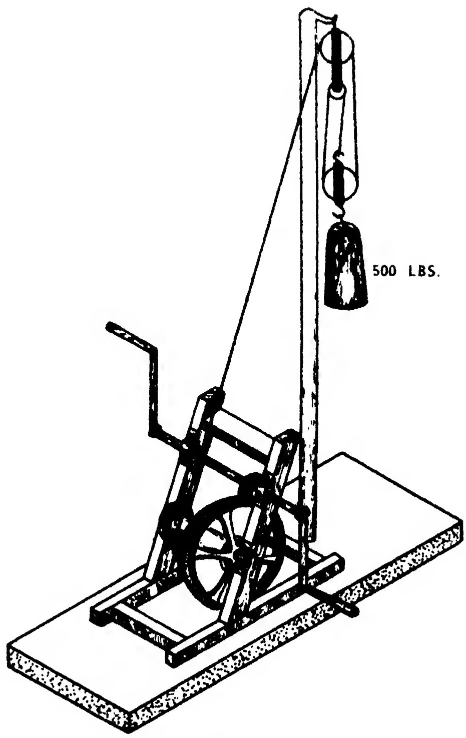

FIG. 138. WINCH.

c) At this same efficiency, how much effort must be used on each crank to lift a roof girder weighing 3 tons?

3. To make great changes in speed, gear trains such as the one shown in Fig. 139 are used.

a) Indicate the direction each gear will turn by placing an arrow on each gear, assuming gear A to be the driver.

b) The driver gears are lettered .... and ...., while the followers are labelled .... and .... Gear .... is an idler, the compound gear being marked by the letters .... and ....

c) The velocity ratio (V.R.) of a gear train is found by dividing the product of the number of teeth on the followers by the product of the

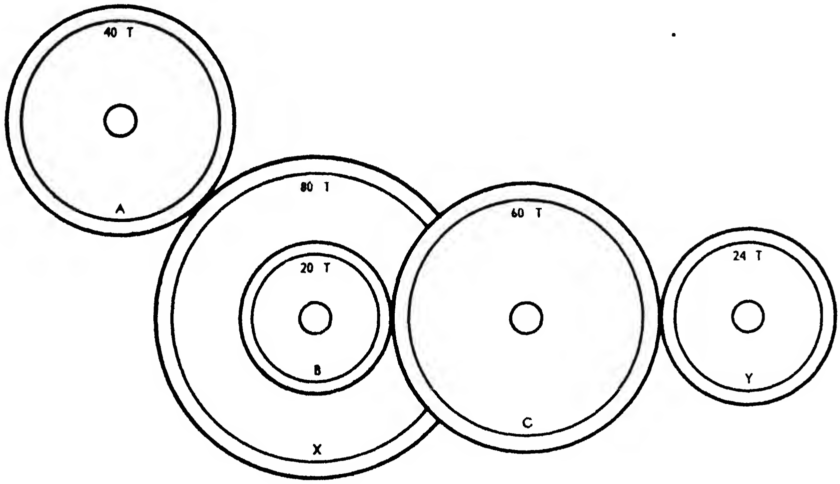

FIG. 139. GEAR TRAIN.

number of teeth on the drivers. Complete the formula to be used in making the calculation of the V. R. of the gear train in Fig. 139 then compute the velocity ratio.

V. R. = ...

d) If gear A makes 1200 r. p. m., find the r. p. m. of gear Y.

e) Remembering that the speed of gears is inversely proportional to the number of teeth, find the speed of gear Y when gear A turns 1800 r. p. m.

f) Were the number of teeth in gear C used in making this calculation? .... Why? ....

4. On the engine lathe, Fig. 140, calculate the speed of the feed screw gear when the head stock gear revolves at 350 r. p. m. (Formula on page 137.)

Gear No.	*No. of teeth*
1	40
2	34
3	28
4	40
5	24
6	104
7	52
8	160
9	70

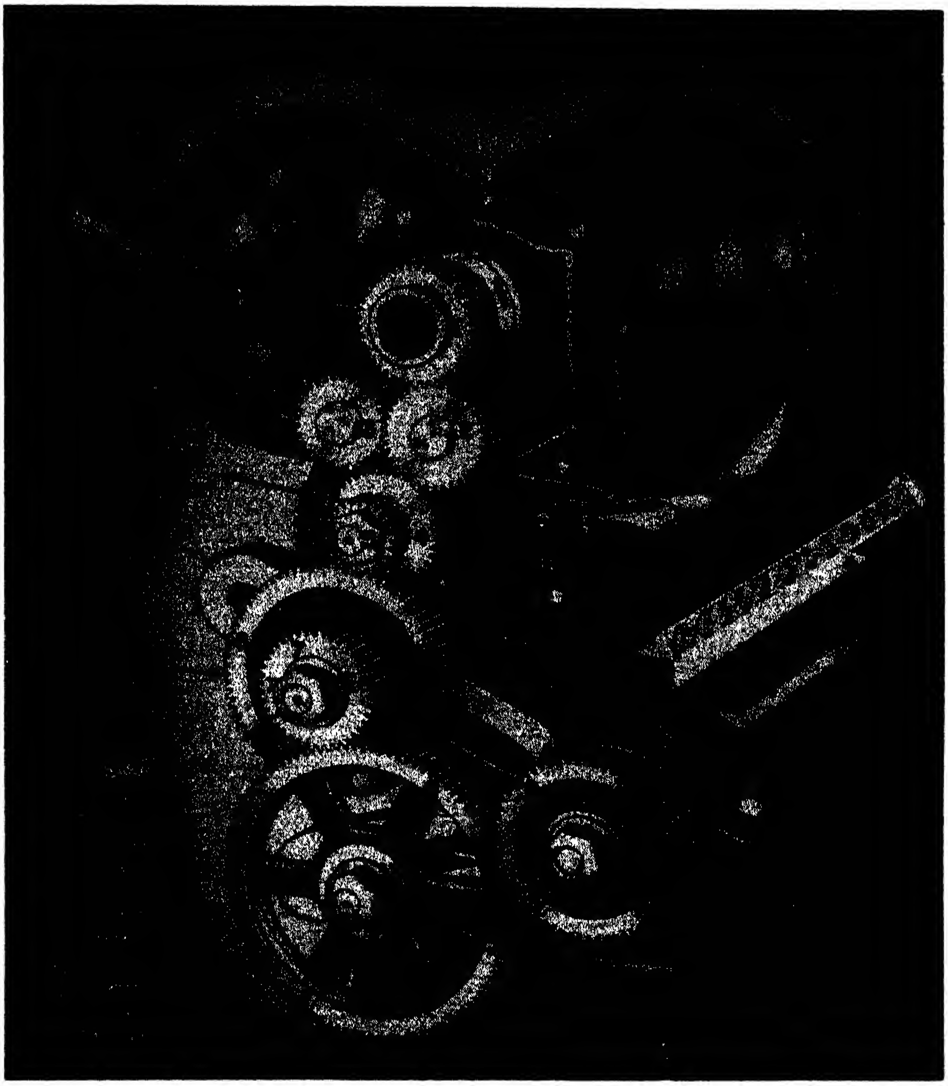

FIG. 140. ENGINE LATHE. (Courtesy, South Bend Lathe Works.)

Formula

$$\frac{\text{Speed of 1st driver}}{\text{Speed of last driven}} = \frac{\text{Product of No. teeth on driven gears}}{\text{Product of No. teeth on driver gears}}$$

BACK GEARED LATHE

When it is desired to turn work in a lathe at a lower speed than can be obtained by using direct drive with pulley No. 4 on the headstock cone, "back gears," Fig. 141 are used. To engage the back gears, the bull gear lock pin is pulled out (see diagram) to disconnect the cone pulley from the spindle, then the back gear lever is pulled forward. The cone pulley should be turned by hand to see that the gears are properly meshed. NEVER PULL THE BACK GEAR LEVER FORWARD WHILE THE LATHE SPINDLE IS REVOLVING. When the back gear is being used,

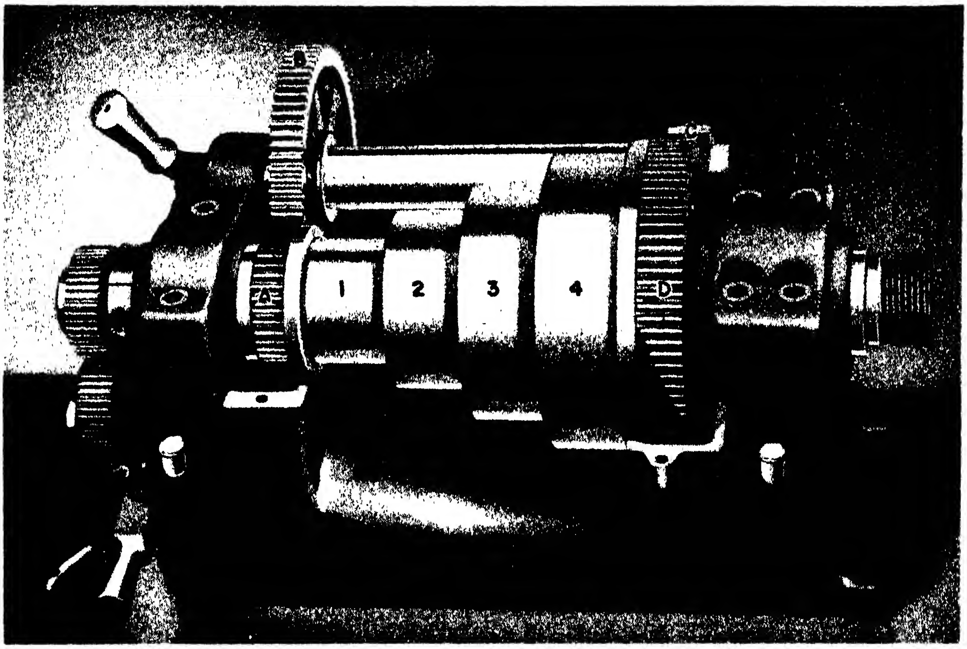

FIG. 141. BACK GEARS. (Courtesy, South Bend Lathe Works.)

power is transmitted from gear A to B, to C, to D and to the spindle.

5. *a)* If gear A has 28 teeth, B, 72 teeth, C, 28 teeth and D, 72 teeth, how fast will the spindle rotate if the cone pulley is turning 128.6 r. p. m.?

   b) If the cone pulley is making 700 revolutions per minute?

AUTOMOBILE GEAR RATIOS

To find the rear axle ratio of an automobile, divide the number of teeth in the differential bevel ring gear by the number of teeth in the drive pinion.

6. *a)* In Fig. 129 the differential bevel gear has 44 teeth while the pinion gear has 12 teeth. Calculate the rear axle ratio. This means that the drive shaft makes .... revolutions for each revolution of the rear axle.

7. Fig. 142 shows the synchromesh transmission of a modern automobile.

   a) In first or low gear, the power from the engine enters the transmission by means of gear No. .... and is transmitted to gear No. .... on the counter shaft.

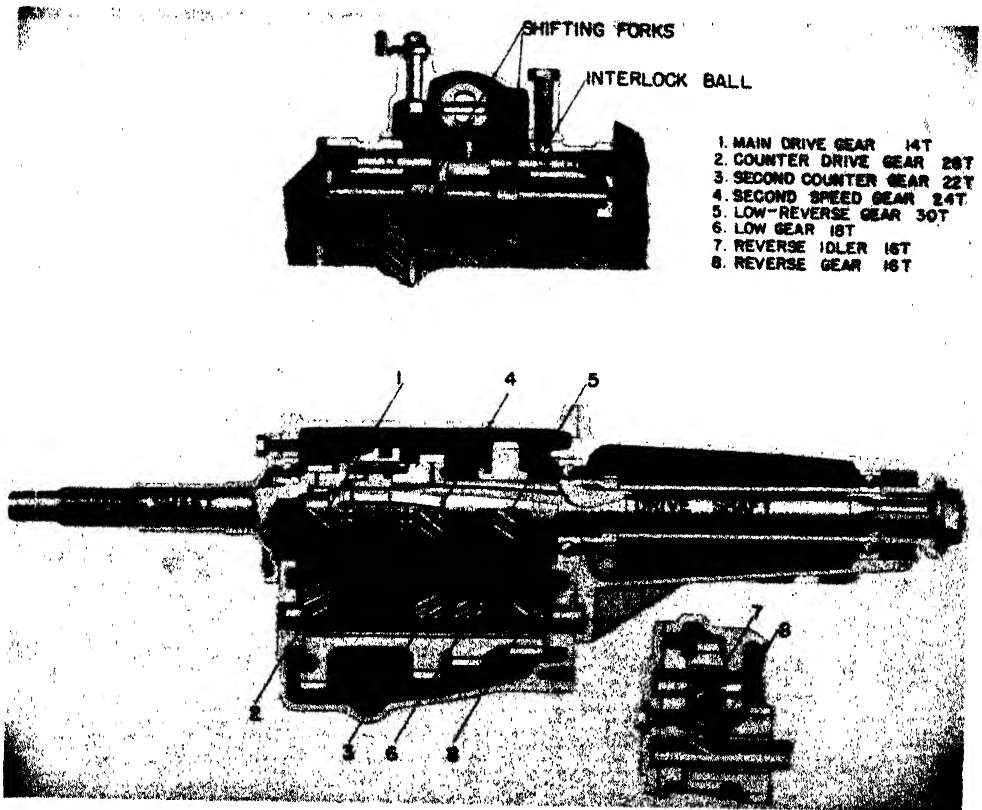

FIG. 142. SYNCHROMESH TRANSMISSION (Courtesy, Chrysler Corporation.)

The power then flows to gear No. ...., then to gear No. .... and then to the drive shaft.

b) Give the gear sequence numbers when the gears are in "second gear." ...., ..., ..., and .... to the drive shaft.

c) Give the gear sequence numbers when the gears are in "high gear." ....to the drive shaft.

d) Give the gear sequence numbers when the gears are in "reverse." ...., ..., ..., ... and .... to the drive shaft.

e) What is the purpose of the idler gear No. 7? ....

....

f) The counter shaft gears (do, do not) .... rotate when the gear shift lever is in "neutral."

To find transmission ratio, divide the product of the number of teeth of the driven gears by the product of the number of teeth of the driving gears.

8. *a)* Find the transmission ratio when the gears (Fig. 142) are in low speed.

Transmission ratio =

This means that in low gear, the engine shaft makes .... revolutions to each revolution of the drive shaft.

b) Find the gear ratio in "second speed."

T. R. =

This means that in second gear, the engine shaft ....

....

c) What is the gear ratio in "high gear"? .... Explain.

....

d) Find the transmission ratio in reverse gear. Remember that gear No. 7 is an idler.

T. R. =

The total gear reduction of an automobile is the product of the transmission ratio and the rear axle ratio.

9. Using the gear ratios in problems 6 and 8, find the total gear reduction.

a) In low gear. *b)* In second gear.

c) In high gear. *d)* In reverse gear.

10. A 10 pitch involute gear has a 5.6″ pitch diameter. How many teeth does the gear have?

11. How do "hypoid" gears differ from "miter" gears? ....

....

....

12. How do "helical" gears differ from "spur" gears? ....

....

....

13. A worm gear has 60 teeth. What is its velocity ratio? ....

Explain your answer. ....

....

14. What measurement of a gear is obtained with a "gear tooth vernier"?

....

15. What is a "herringbone" gear? ....

.... What advantages do herringbone gears have over other types of gears? ....

....

16. Distinguish between a "rack" and a "pinion" gear. ....

....

17. Give two examples of a worm gear in use. ....

....

....

Where are internal gears used? ....

....

18. In gear work, what do the terms "addendum" and "dedendum" mean?

a) Addendum ....

....

b) Dedendum ....

....

HYDRAULICS

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Fletcher: *Unified Physics*, pages 25-38.
Holley and Lohr: *Mastery Units in Physics*, pages 69-84.
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TM-10-570, *Internal Combustion Engine*, pages 64-65.

HYDRAULICS

In addition to the six simple machines previously discussed, the principle of the hydraulic press is utilized in many machines. The hydraulic brake, jack and service station lift are common examples. Liquids exert force on the bottom and sides of their container in proportion to their depth, density and the surface area covered, that is

Total force = depth x density x area

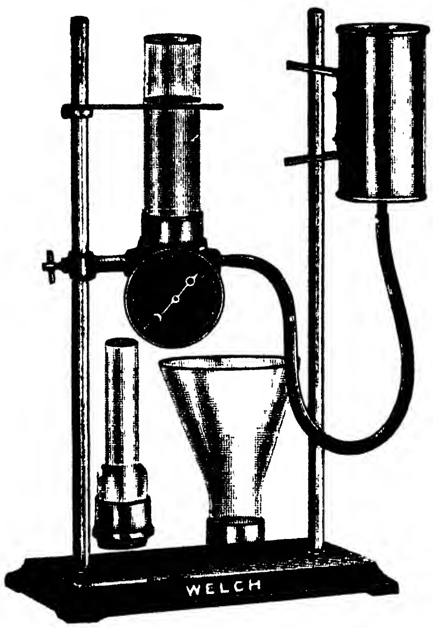

FIG. 143. PASCAL'S VASES. (Courtesy, W. M. Welch Scientific Co.)

Pressure exerted by a liquid is considered to be the weight of the liquid pressing on a unit of area such as a square foot, square inch or square centimeter. The shape of the container does not affect the pressure exerted by a liquid. Pascal's Vases (Fig. 143) show that for the same depth of liquid the pressure is the same regardless of the shape of the container. Water pressure is maintained in city water mains or in factories by water tanks or reservoirs mounted at a high altitude.

Liquids push upward also. This fact has been observed by anyone who has tried to push a floating object beneath the surface of a liquid. In fact, the upward pressure exerted by a liquid at any depth is equal to the downward pressure exerted by the same liquid at the same level.

Liquids are nearly incompressible and because of this, transmit pressure undiminished to all parts of an enclosed container. This fact, known as Pascal's law, is the principle upon which the hydraulic press operates.

THE HYDRAULIC PRESS

A hydraulic press used in mounting freight car wheels is shown in Fig. 50. Fig. 144 illustrates the application of Pascal's principle to the hydraulic press. This press consists of two cylinders, one of small diameter and one

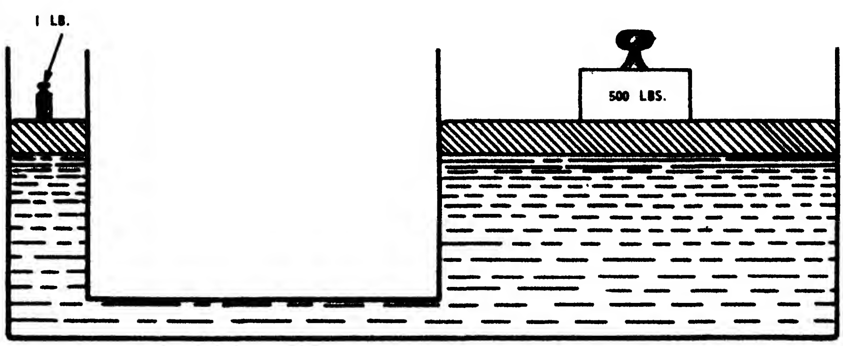

FIG. 144. THE HYDRAULIC PRESS PRINCIPLE.

of large diameter, joined by means of a small pipe or tube and fitted with leakproof pistons. Pressure exerted on each square unit of area on the small piston is transmitted undiminished to each unit of area on the large piston (Pascal's law). If the area of the large piston is 500 times that of

the small piston, one pound of force on the small piston will lift a 500 lb. resistance placed on the large piston (disregarding friction).

Fig. 145 shows the construction of a hydraulic automobile jack. The small piston (p) draws oil from the reservoir on the up-stroke and forces it under the large piston (P) on the down-stroke. The mechanical advantage of the hydraulic press, exclusive of the lever handle, is found by dividing the area of the large piston by the area of the small piston.

$$\text{M. A.} = \frac{\text{Area P}}{\text{area p}}$$

Since the areas of two circles are proportional to the square of their diameters, then

$$\text{M. A.} = \frac{D^2}{d^2}$$

where D = diameter of large piston (P) and d = diameter of small piston (p)

FIG. 145A. HYDRAULIC JACK.

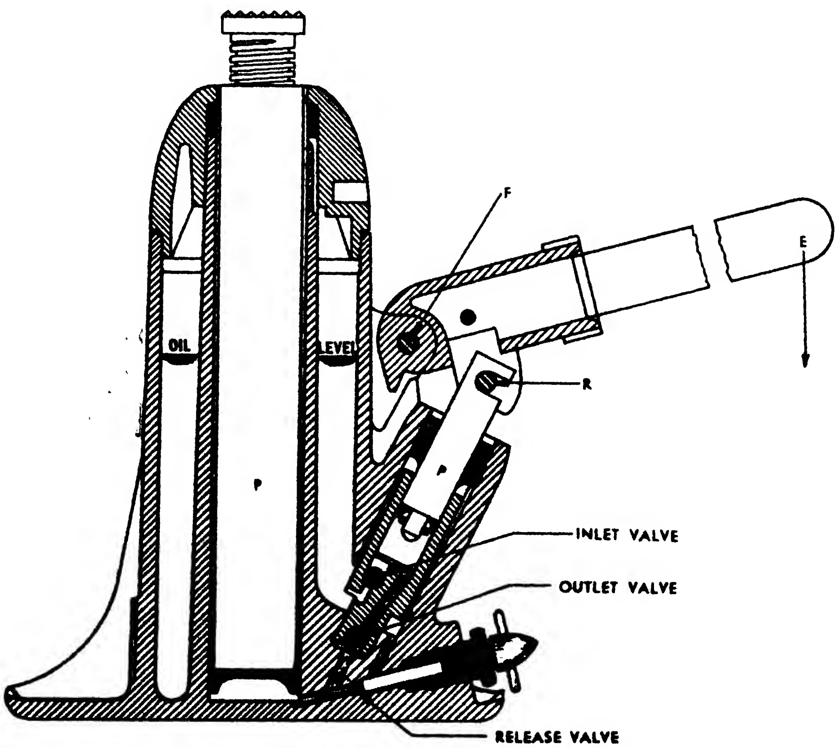

FIG. 145B. SECTIONAL VIEW OF A HYDRAULIC JACK.

To find the M. A. of the automobile jack in Fig. 145, the mechanical advantage of the lever must be determined. It is EF/RF in this figure. Since the M. A. of a compound machine is the product of the mechanical advantages of the separate machines of which it is made, the mechanical advantage of the jack is

$$\frac{D^2}{d^2} \times \frac{EF}{RF}$$

The hydraulic jack is used to gain force but no energy is gained. This will be evident when the distance the effort moves is compared with the distance the resistance moves.

THE HYDRAULIC AUTOMOBILE JACK

Purpose:

1. To use the hydraulic automobile jack in studying the principle of the hydraulic press.
2. To determine the mechanical advantage and efficiency of the hydraulic jack.

Tools and Materials:

Hydraulic jack (1½ ton capacity)
Special 7 feet lever bar
Heavy weight (50 lbs.)
Small weights and weight hanger
Meter or yard stick

Procedure:

Weigh the wooden bar and locate its center of gravity by balancing it over a knife edge support. Set up the apparatus as shown in Fig. 146A,

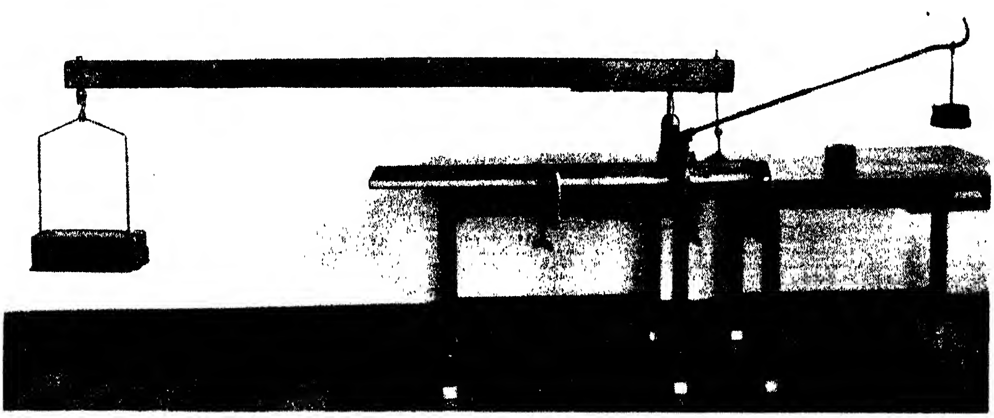

FIG. 146A. FINDING THE EFFICIENCY OF A HYDRAULIC JACK.

locating the jack about 6 inches from the fulcrum. Hang a 50 lb. weight on the weight hook at the end of the bar. Measure the distances (FR), (FC) and (FW), recording them in the proper places in Fig. 146B. Also place the weight of the bar in the block marked (C) and the weight on the end of the bar in the block marked (W). Using the principle of moments, calculate the total pressing force on the jack at (R).

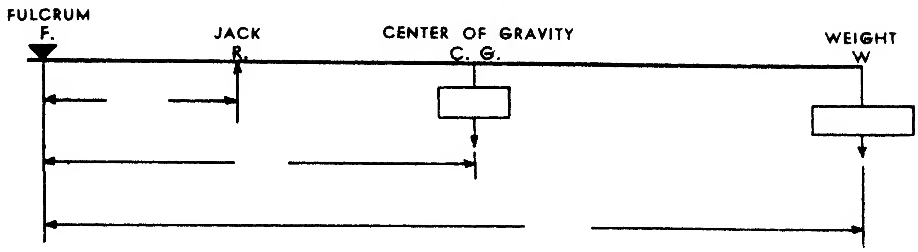

FIG. 146B. LEVER PROBLEM ON HYDRAULIC JACK.

Calculations

Now measure (F′R′) and (F′W′) on the jack handle (remember that the lever arm must be measured perpendicular to the direction of action.) Also measure the diameters of the small and large pistons. Hang weights at (W′) on the jack handle until the weight (W) is lifted. Weigh the jack handle (W″). This acts at its center of gravity. Record this information in Table XXXII.

W′	*F′R′*	*F′W′*	*Diameter D*	*Diameter d*	*W″*	*F′W″*	*Resistance on Jack (R)*	*Calculated * Resistance*	*Efficiency R/calculated R*

TABLE XXXII

* If the jack were frictionless, the resistance which it would overcome is calculated by the formula

$$\text{Calculated Resistance} = \left(W' \times \frac{F'W'}{F'R'} \times \frac{D^2}{d^2}\right) + \left(W'' \times \frac{F'W''}{F'R'} \times \frac{D^2}{d^2}\right)$$

Make this calculation using the measurements found in Table XXXII. Also calculate the efficiency of the jack.

Calculate the M. A. of the hydraulic jack which was used.

Questions and Problems:

1. What is the meaning of the term "hydraulic"? ....

....

2. Using the hydraulic press as an example, illustrate the difference between "force" and "pressure." ....

....

....

....

3. What is Pascal's Law? ....

....

....

4. The hydraulic press shown in Fig. 147 has a small piston of $\frac{7}{8}''$ diameter and a large piston of $3''$ diameter. A pull of 100 lbs. is exerted

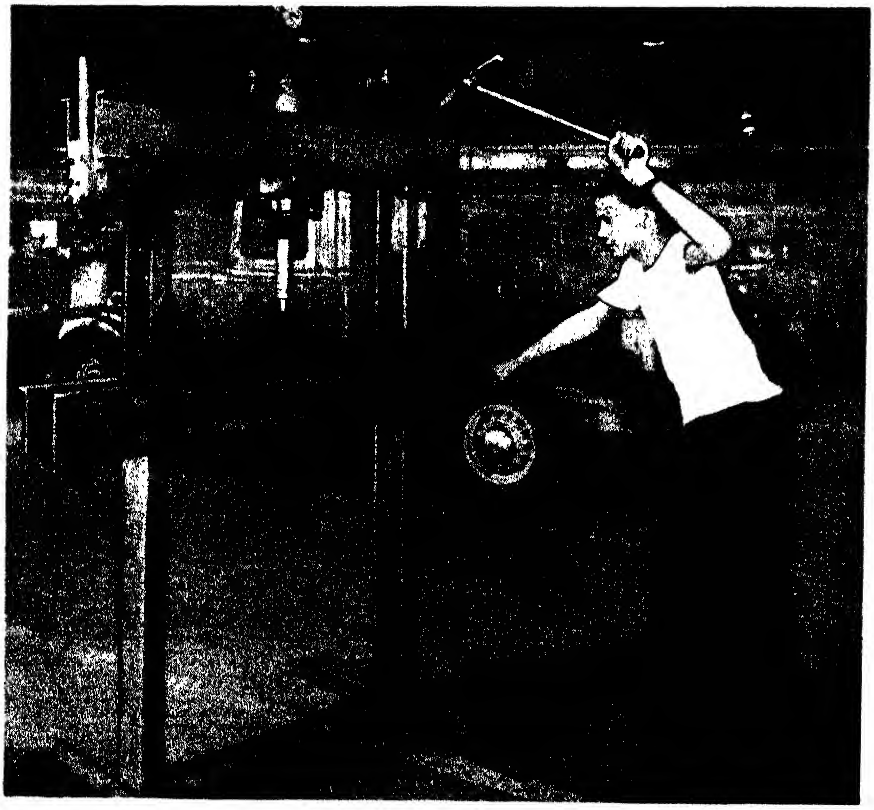

FIG. 147. HYDRAULIC PRESS FOR STRAIGHTENING AUTOMOBILE AXLES

on the lever handle 3 feet from the fulcrum and the small piston is connected $1\frac{1}{2}$ inches from the fulcrum. Find the total force exerted by the press, assuming an efficiency of 78%.

HYDRAULIC BRAKES

The hydraulic brake used on automobiles is the most common application of the hydraulic press principle. The working parts of this type of brake are the main or master cylinder, and the wheel cylinders. Fig. 148 shows the construction of the master cylinder.

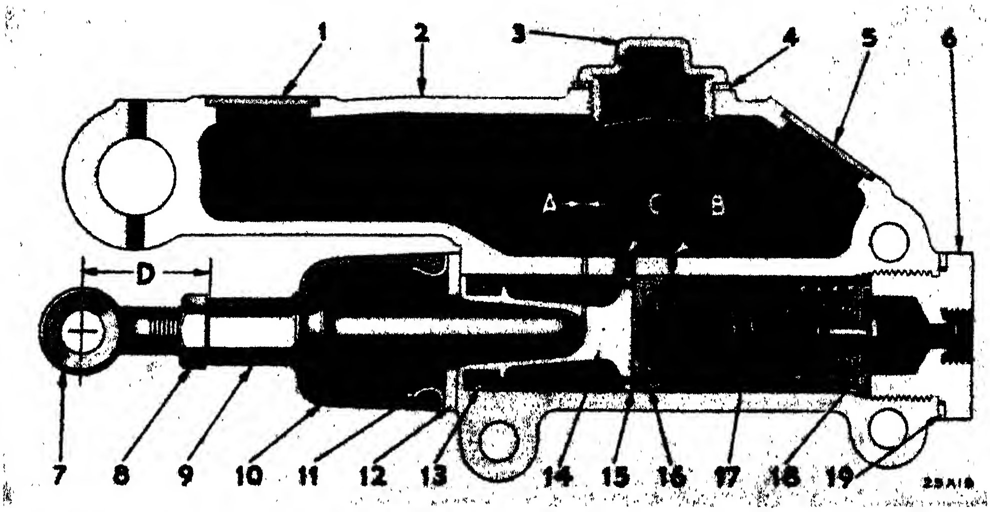

FIG. 148. HYDRAULIC BRAKE MASTER CYLINDER. (Courtesy, Chrysler Corporation.)

The piston (14) in the master cylinder is operated by force applied on the rod (7) connected to the brake pedal. As force is applied, the primary cup (16) closes the compensating port (B) and fluid is forced through the holes in the outlet valve (18), into the pipe lines and wheel cylinders. This pressure forces the pistons in the wheel cylinders outward, expanding the brake shoes, Fig. 149, against the drums. As the pedal is depressed farther, higher pressure is built up within the hydraulic system, causing the brake shoes to exert greater force against the brake drums.

As the pedal is released, the hydraulic pressure is released and the retracting springs, Fig. 150, draw the shoes together, pressing the wheel cylinder pistons inward and forcing the fluid out of the wheel cylinders back into the lines toward the main cylinder. The piston return spring (17) in the main cylinder, returns the piston to the pedal stop faster than the brake fluid is forced back into the lines, creating a slight vacuum in that part of the cylinder ahead of the piston. This vacuum causes a small amount of liquid to flow through the holes in the piston head (14), past the lip of the primary cup (16), and into the forward part of the cylinder. This action keeps the cylinder filled with fluid at all times, ready for the next brake application. As the fluid is drawn from the space behind the piston head, it is replenished from the reservoir through the breather port (C). When the piston is in a fully released position, the primary cup clears the compensating port (B), allowing excess fluid to flow from the cylinder into the reservoir as the brake shoe retracting springs force the fluid out of the wheel cylinders.

Some late model cars have two separate wheel cylinders as shown in

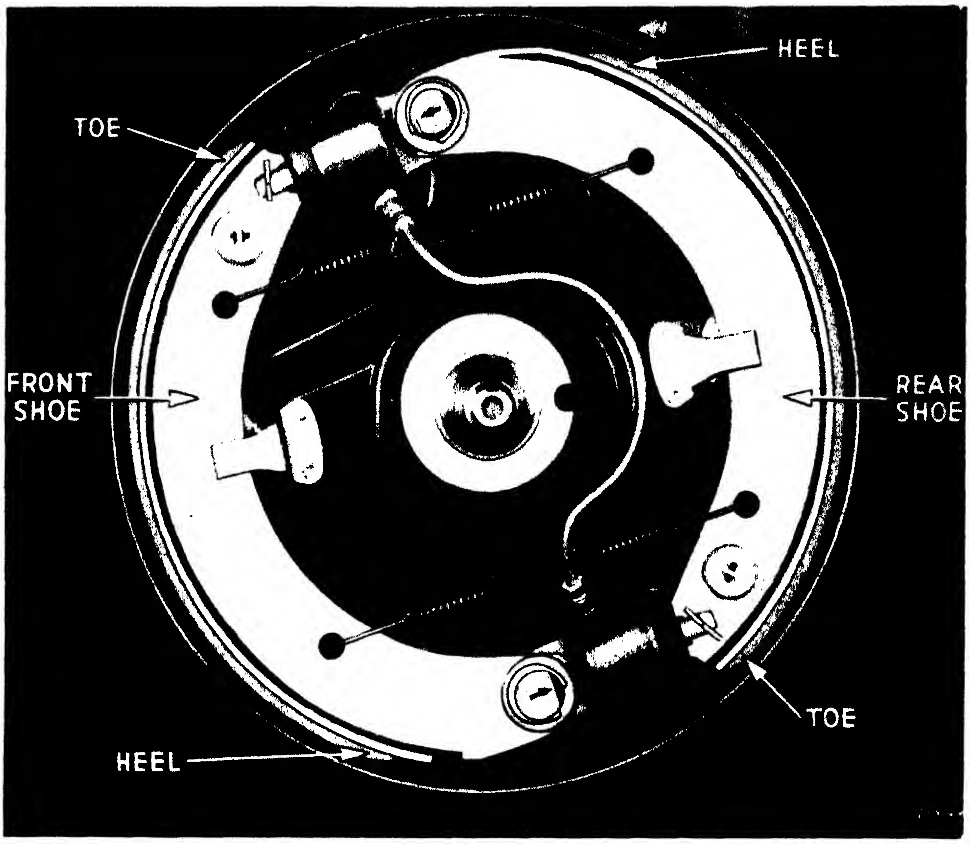

FIG. 149. BRAKE SHOES AND HYDRAULIC CYLINDERS. (Courtesy, Chrysler Corporation.)

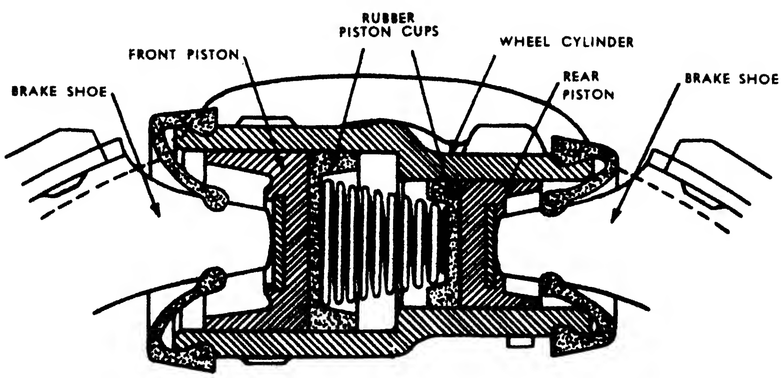

FIG. 150. HYDRAULIC BRAKE WHEEL CYLINDER.

Fig. 149. This allows both brake shoes to act exactly alike, making it unnecessary to use different size brake shoes on the front and rear.

Many cars have a single wheel cylinder as shown in Fig. 150.

Problem:

The diameter of the pistons used in an automobile hydraulic brake

are as follows: front $1\frac{3}{32}''$; rear 1″. The diameter of the piston in the master cylinder is one inch.

a) If a force of 5 lbs. is exerted on the brake pedal (M.A. of 10) What is the pressure per square inch on the main piston? On each wheel piston?

b) What is the total force exerted on the main piston? On the front piston in the wheel cylinder? On the rear piston of the wheel cylinder?

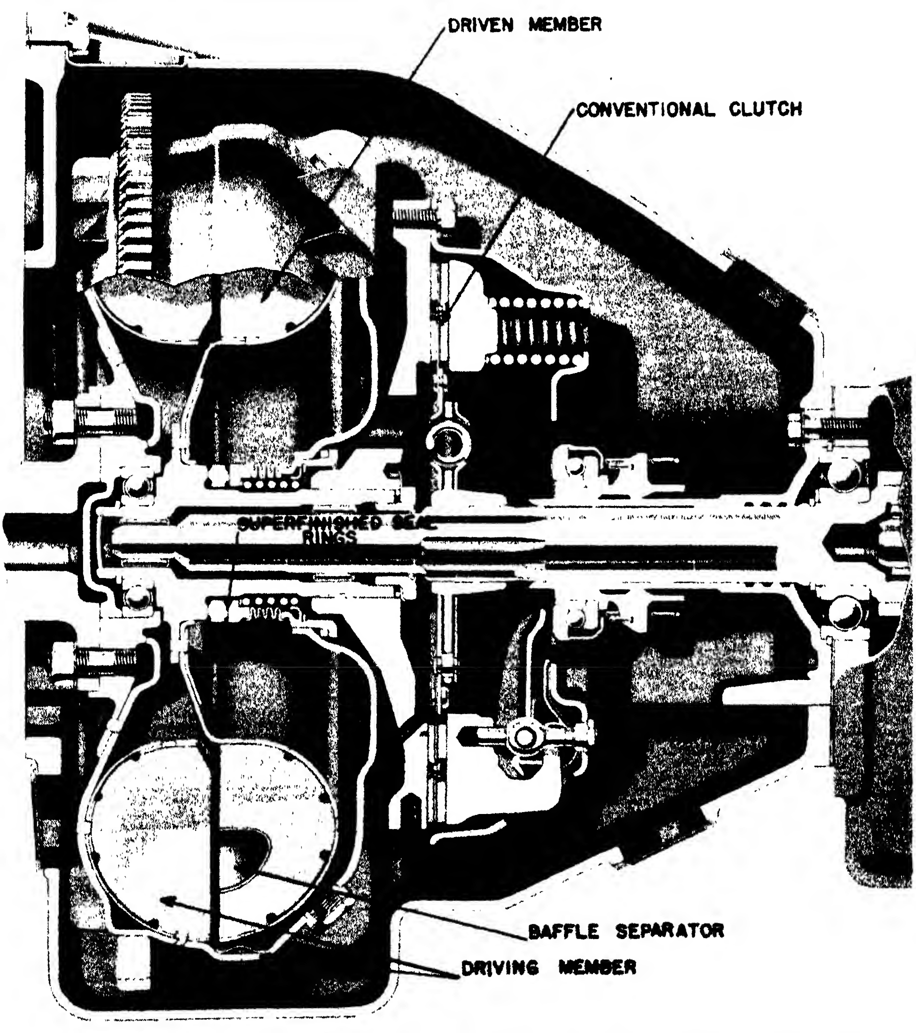

FIG. 151. HYDRAULIC COUPLING (FLUID DRIVE). (Courtesy, Chrysler Corporation.)

c) The front brake band is $9\frac{15}{16}''$ x $1\frac{3}{4}''$; the rear band $12\frac{3}{4}''$ x $1\frac{3}{4}''$. Find the pressure on each brake band.

FLUID COUPLING

Fluid coupling as used in the automobile is often known as the "hydraulic clutch." Fig. 151 shows the construction of such a coupling. The driving member and driven member of the coupling are constructed of many baffle plates so that oil is circulated efficiently. This is a splendid example of "fluid friction," as it is the friction between the molecules of oil which causes this type of drive to operate. Note that the conventional clutch disks are also present but seldom need to be used. This type of coupling permits smoother and easier driving.

HYDRAULIC SHOCK ABSORBERS

Shock absorbers, not only give greater riding comfort but also perform other important tasks. Rear wheels bouncing over small bumps, spin while in the air, causing the rubber to be scuffed off when the tires again contact the ground. There is also a loss of traction which affects gasoline economy. Good steering is more or less dependent on the proper performance of the shock absorber. Shock absorbers should dampen the jar a front wheel receives upon hitting a sharp bump. Inoperative absorbers permit this jar to be transmitted to the steering wheel, which results in steering wheel whip or "fight."

The construction of a common type of hydraulic shock absorber is shown in Fig. 152. It operates as follows:

COMPRESSION STROKE

When the car spring is being compressed, the piston moves toward the lower end of the cylinder. Fluid is forced through the relief valves in the piston, lifting the valve plate and entering the upper pressure tube. The volume of fluid thus displaced by the piston rod, is forced out of the lower chamber through the valve orifice into the surrounding reservoir. As this opening is below the level of the fluid in the reservoir, no emulsion of air and fluid can be formed. The resistance to the vehicle spring travel is determined by the orifice in the valve and in the strength of the valve disks.

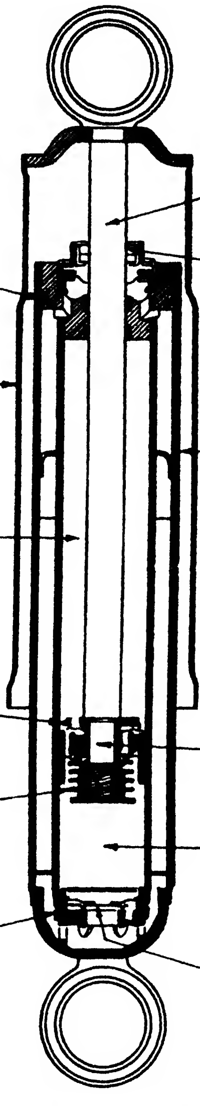

FIG. 152. HYDRAULIC SHOCK ABSORBER.

REBOUND STROKE

When the car rebounds, the resistance is instantly effective. As the piston is pulled up, the fluid in the pressure tube is forced through the slot in the valve plate, through holes in the piston, against the orifice plate. As the pressure increases, fluid is forced through the orifice, compresses the rebound valve spring and lifts the orifice plate from the valve seat, letting fluid pass into the lower chamber. Since the piston rod is moving out of the pressure chamber, the added displacement is compensated for by a return flow of fluid, drawn into the lower chamber from the surrounding reservoir through the intake relief valve. The valve plate is lifted off its seat in this operation allowing fluid to fill the inner chamber.

MACHINES UTILIZE PROPERTIES OF MOLECULES

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 152-159.
Dull: *Modern Physics*, pages 89-93.
Fletcher: *Unified Physics*, pages 13-23.
Holley and Lohr: *Mastery Units in Physics*, pages 20-36.
Millikan: *New Elementary Physics*, pages 74-82.

BROWNIAN MOVEMENT

The statement was made in the discussion of the composition of matter, that all substances are composed of tiny particles called molecules. According to the kinetic molecular theory, molecules are in constant motion. Up to the present time, an individual molecule has not been seen, but many commonplace phenomena, such as the ability of an air-filled tire to hold up the weight of an airplane weighing several tons, can be explained only in terms of molecular motion.

About one hundred and twenty-five years ago, an English botanist, named Brown, noticed that tiny particles suspended in an enclosed space filled with a liquid or a gas, exhibited a peculiar dancing motion. He diagramed their motion and found their path to have no definite pattern. (See Fig. 153A.) It is now known that the particles possess a random motion due to their temperature energy. During their motion the particles bump into molecules of the medium in which they are suspended. This bombardment of microscopic and ultra-microscopic particles by other

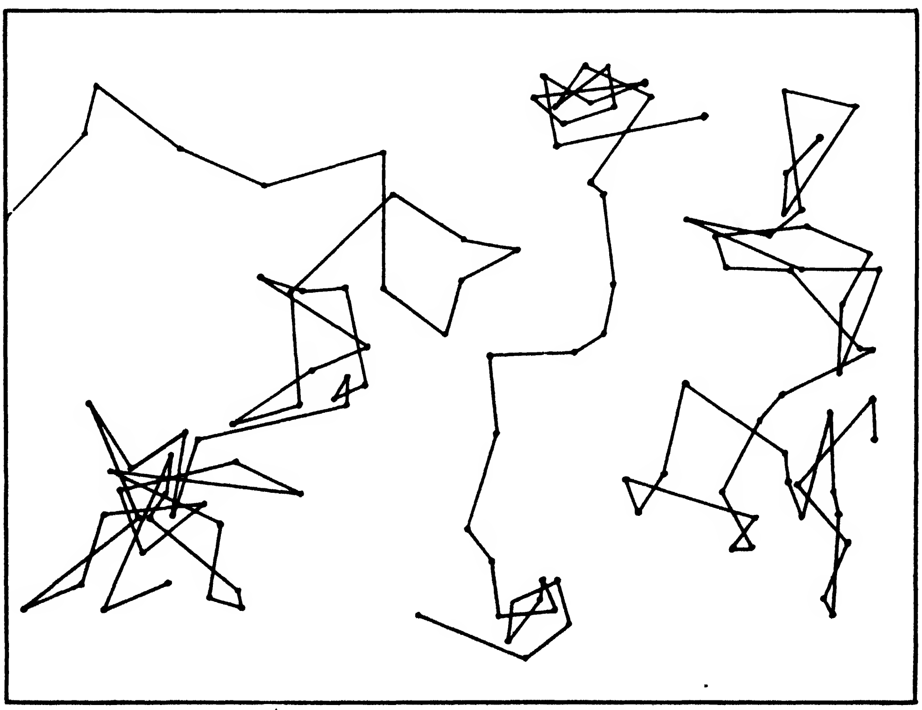

FIG. 153A. THE BROWNIAN MOVEMENT.

molecules, causes the random motion of the suspended substances known as "Brownian movement."

The student may observe the Brownian movement by placing a drop of water, containing a tiny particle of carmine dye on a microscope slide and viewing it at low magnification. The Brownian movement is also well illustrated by the motion of smoke particles. Smoke may be observed under the microscope, if it is trapped in a glass box and illuminated from

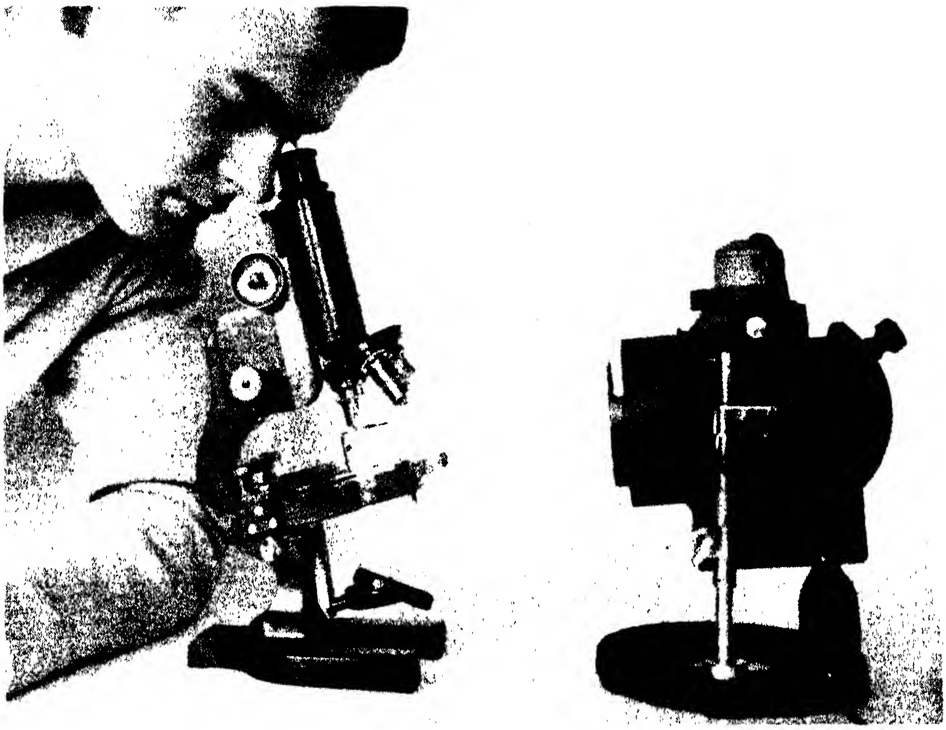

FIG. 153B. OBSERVING BROWNIAN MOVEMENT.

the side. See Fig. 153B. The Brownian movement can best be seen by selecting one smoke particle and following it with the eye as it is jostled around by the molecular bombardment.

MOLECULES ATTRACT EACH OTHER

By means of molecular motion we can explain many common physical phenomena. The attraction of like molecules for one another, and the attraction of unlike molecules to each other, may be explained by the theories of molecular motion.

Cohesion is the attraction between like molecules of a substance. Adhesion is the molecular force which holds molecules of unlike substances together.

The molecules of a substance are held together by an interlocking force of attraction. When an external force tends to move molecules from their normal position, they resist such change with a force equal to their inter-molecular attraction. The force of attraction of one molecule for another varies with different kinds of molecules. The force of cohesion is

greatest in solids, less in liquids, and practically non-existant in gases. The adhesion between unlike molecules is due to an interlocking of molecular bonds. When two substances are pressed tightly together, the molecules of one are attracted to the molecules of the other. At the area of contact there is an intermingling of molecular paths.

It is natural for molecular motions and attractions to be in equilibrium, for molecules oppose any force that seeks to change their condition. Work must be done to pull apart attracting molecules. A measure of the force required to do this work is called adhesion.

COHESION AND ADHESION — A DEMONSTRATION

A. A simple demonstration will illustrate the forces of cohesion and adhesion. To the left-hand side of a beam balance, suspend a smooth glass disk. See Fig. 154. Counter balance the weight of the disk by adding

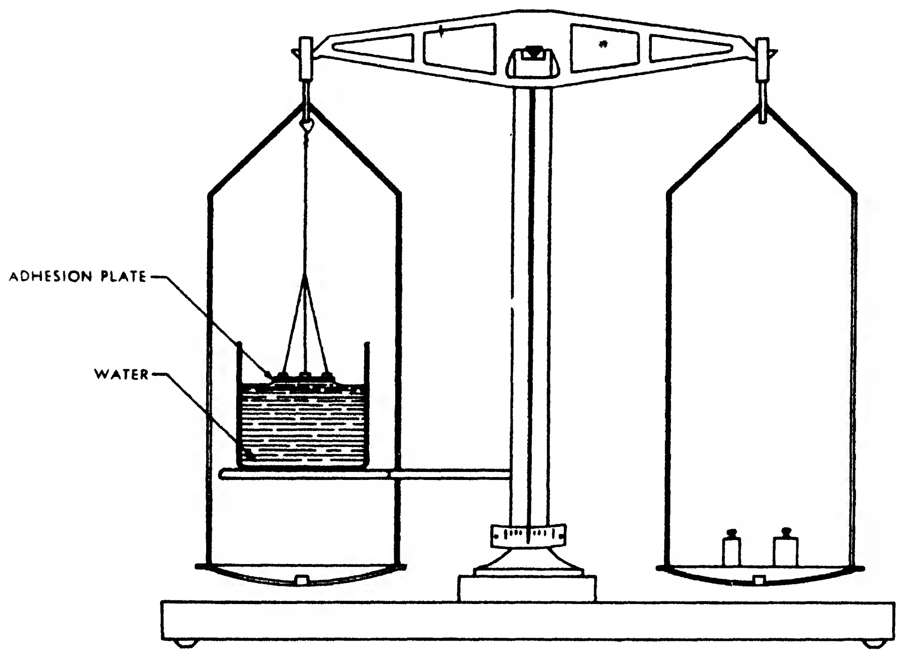

FIG. 154. MEASURING THE FORCE OF ADHESION.

weights to the right-hand pan. Record this weight in the spaces which follow.

Bring a dish of water up to the under surface of the disk so that it just touches the surface of the water. The disk will adhere to the water. Now add weights to the right-hand pan until the glass disk is pulled away from the surface of the water. Record the total weight on the right-hand pan.

Examine the under side of the glass disk for evidence of clinging drops of water.

Questions:

The weight of the disk is................ The amount of weight required to pull the disk from the water is .... The difference be-

tween these two weights is .... This value represents the .... of glass for the .... The presence of water drops clinging on the bottom of the disk, is evidence that the (cohesive, adhesive) .... force of glass for water is .... than the .... force between water molecules.

B. Repeat part (A) using a dish filled with mercury instead of water. Record the weights in the same manner. Examine the under side of the glass disk for evidence of mercury drops.

Questions:

The adhesive force between the mercury and the glass disk measures .... grams. This adhesive force is (more, less) .... than the adhesive attraction of glass for water. The fact that drops of mercury (were, were not) .... present on the bottom of

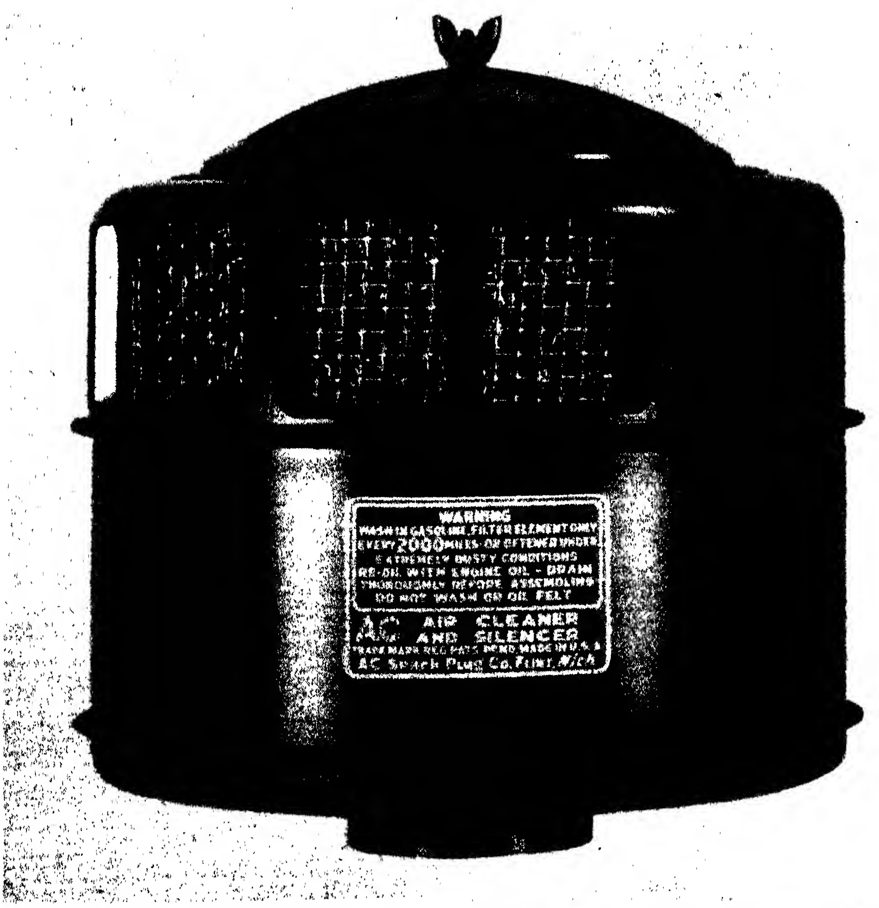

FIG. 155A. OIL WETTED MESH TYPE AIR CLEANER. (Courtesy, A. C. Spark Plug Division, General Motors Corporation.)

the disk indicates that the .... force of mercury molecules for glass molecules is (more, less) .... than the .... force of mercury molecules for mercury molecules.

AIR CLEANERS — AN APPLICATION OF ADHESION

The average gasoline engine sucks 10,000 gallons of air through the carburetor for each gallon of fuel used in its operation. This quantity of air at atmospheric pressure would occupy a space 132 inches high, 132 inches long and 132 inches wide. The air contains some abrasive dust, lint, soot, ash and other particles, the quantity varying with the time, place and other conditions. Air cleaners placed upon the carbureter intake. remove much of this contaminating material. Air cleaners are also used on the crankcase filler tubes, ventilated type generators, vacuum and pressure brake systems, vacuum gear shift mechanisms, and fresh air intakes on car heaters.

Two common types of air filters are in use (a) the oil wetted mesh

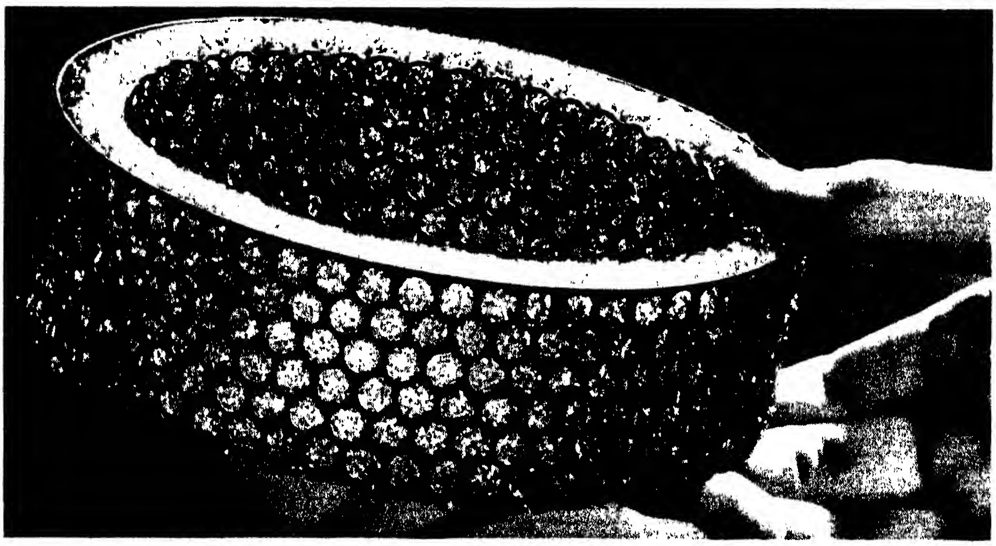

FIG. 155B. FILTERING ELEMENT (Courtesy, A. C. Spark Plug Division, General Motors Corporation.)

type and (b) the oil bath type. Fig. 155A shows a cleaner of the first type, having a removable filtering element, Fig. 155B. This consists of a mesh of copper turnings saturated with motor oil of SAE 50 grade. As the air passes through the spaces of the copper gauze, the particles of dirt, dust and grit *adhere* to the oil covered edges of the gauze. To keep the filter operating efficiently, the gauze should be removed from time to time and cleaned by dipping in gasoline. After drying, it is again dipped in engine oil, drained and re-assembled in the metal container. Fig. 155C illustrates a louvre type air cleaner in which the filtering material is arranged in the form of a hollow cylinder, this material being permanently installed in a sheet metal can having a large number of louvres (openings). A filter,

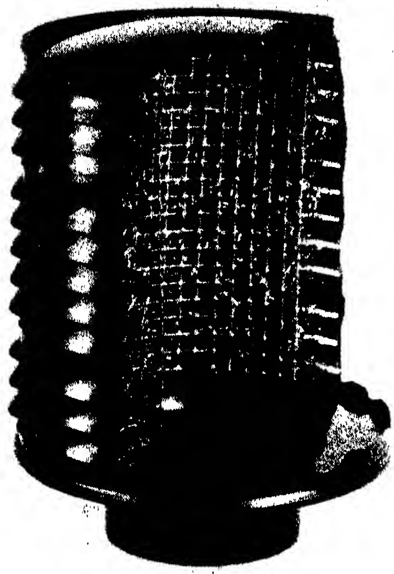

FIG. 155C. LOUVRE TYPE AIR CLEANER. (Courtesy, A. C. Spark Plug Division, General Motors Corporation.)

FIG. 155D. CRANKCASE BREATHER AIR CLEANER. (Courtesy, A. C. Spark Plug Division, General Motors Corporation.)

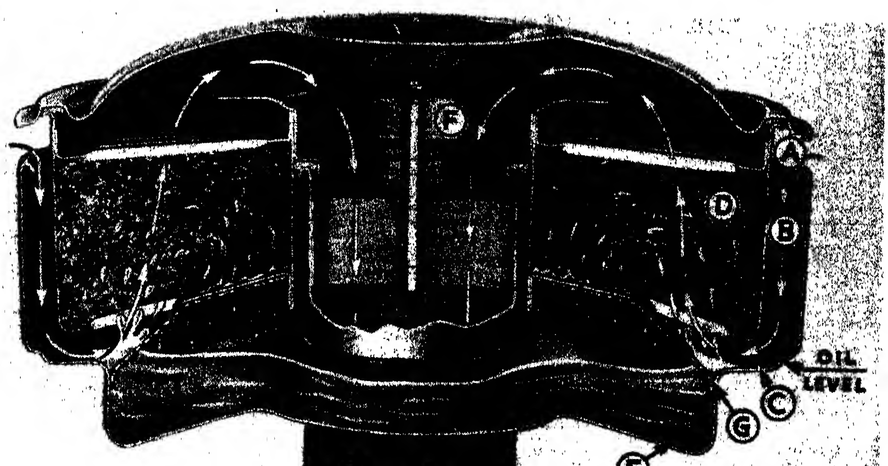

FIG. 155E. OIL BATH TYPE AIR CLEANER. (Courtesy, A. C. Spark Plug Division, General Motors Corporation.)

used to clean the air drawn through the breather pipe into the crankcase is shown in Fig. 155D. This acts as a cap for the oil filter tube also.

Fig. 155E is an air cleaner of the oil bath type. Air entering at (A-B) makes a sudden change of direction (C) over a bath of oil thereby dropping a large part of its dust load (E) into the oil. The air then passes through the oil wetted mesh (D) where the smaller dust particles adhere, then on to the carburetor through (F). This type of cleaner has the additional

advantage of a constantly washed cleaning element. This is accomplished by a steady stream of oil picked up by the air from the oil bath reservoir in the base of the cleaner. An oil baffle (G) is provided between the oil reservoir and the filtering mesh so that sufficient oil is drawn upward to moisten and clean the element, but not enough to impede air passage and cause oil to be drawn into the carburetor.

COHESION AND ADHESION IN SOLIDS

The forces of cohesion and adhesion determine to a large degree the physical properties of solids. The physical properties of solids described as elasticity, tenacity, and tensile strength, are due primarily to the ability of molecules to hold to each other. Since molecules tend to hold to each other, the forces required to cause bending, twisting, shearing and stretching, are resisted by the cohesive and adhesive forces (stress) within a body.

In dealing with the materials of which machines are made, the factor of safety must at all times be considered. In determining proper working stresses, the strength of the material being used and its elastic limit must be known. The ratio of the strength of the material to the working stress is called the "factor of safety." This ratio represents the number of times the external force on a material may be increased before the material fails. These ratio numbers are established by law or by common practice. Since the elastic limit is lower than the ultimate strength of materials, it is quite logical to consider it in determining the factor of safety.

FACTORS OF SAFETY

Material	*Use*	*Factor*
Steel	Buildings	4
Steel	Bridges	5
Steel	Pistons & connecting rods	9 - 12
Steel	Mill shafting	24
Cast iron	Machines	20
Wrought iron	Machines	10

ELASTICITY — HOOKE'S LAW

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 145-159.
Dull: *Modern Physics*, pages 4-13; 89-104.
Elberfield: *Strength and Properties of Materials*, pages 17-23.
Fletcher: *Unified Physics*, pages 13-22.
Merriman: *Strength of Materials*, pages 9-18; 63-66; 108-120.
Millikan: *New Elementary Physics*, pages 74-81, 131-142.

The most outstanding property of solids with reference to machines, is their ability to resist a change in shape. This change in shape may take the form of elongation, twisting, bending, compression or shearing. In all of these changes, cohesive forces between molecules tend to prevent any alteration of shape. The body, if deformed by force, will return to its original shape when the force is removed, provided the elastic limit of the substance has not been reached.

A force placed upon a body is known as a stress. It is the force tending to produce a change in shape of the body. The total change in shape a body undergoes is called *total strain,* while the change in shape per unit of measurement, is called the *unit strain.* When a material is under tensile load, the strain is called elongation, with a twisting load it is called torsion. Two forces, pushing in opposite directions at a point, tend to produce a shearing strain.

The stress applied to a body may be so great as to cause rupture or breaking. Before rupture takes place, a given material passes through several phases of a stress-strain relationship. In 1678 Robert Hooke made a study of the relationship of stress to strain and discovered a Law of Materials that bears his name — Hooke's Law. Hooke found that as a stress is placed upon a body it deforms the body a definite amount, increasing proportionally as the stress is increased. If a given material is subjected to increasing stresses until rupture occurs and the strain is noted at several points, the resulting data may be plotted to form a curve as shown in Fig. 156.

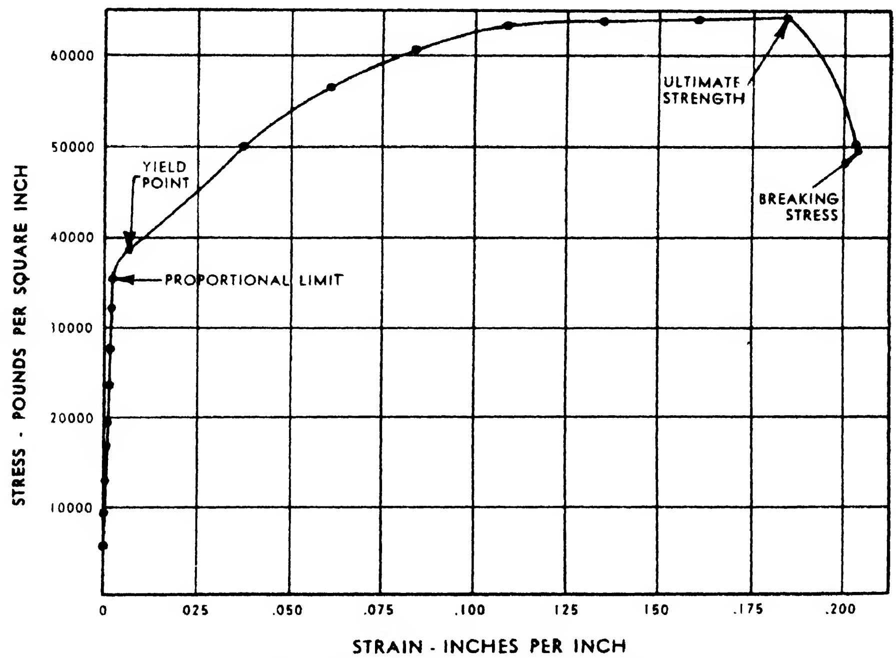

FIG. 156. A STRESS-STRAIN GRAPH.

It may be seen that the strain is proportional to the stress, up to the *elastic limit.* Beyond this point, the strain is greater for a unit increase of stress, than below the point. A body, strained beyond its elastic limit, will not resume its former shape when the stress is removed.

The *yield point* is the point at which there is an increase in the strain without a corresponding increase in stress.

The *ultimate stress* is the greatest stress that may be placed upon a body without rupturing it. Beyond this point, breaking occurs.

New Words:

ADHESION.—The force causing unlike molecules to stick together.

COHESION.—The force holding similar molecules together.

ELASTICIITY.—The ability of a body to return to its former size or shape after being subjected to a stress.

STRAIN.—The amount of change in the shape of a body caused by a deforming force.

STRESS.—The amount of force placed upon a body.

YIELD POINT.—The point, beyond the elastic limit, where a body remains permanently distorted by a stress.

Additional New Words:

______________________ ....

....

______________________ ....

....

______________________ ....

....

______________________ ....

....

______________________ ....

....

MEASURING ELASTICITY — (HOOKE'S LAW)

Purpose:

1. To verify Hooke's law.
2. To study the stress and strain relationship in stretching, bending and twisting.
3. To calculate the strength factors of materials.

Part A. — Tension

Tools and Materials:

Steel coil spring	Iron stand
Weight holder with pointer	Clamps
Meter stick	Slotted iron weights

Introduction:

The elasticity of springs is made use of in automobiles — to absorb shocks and to close valves; in houses — to close doors or raise window shades. The elasticity of a coiled spring drives watch and clock mech-

anisms. When a body is deformed, potential energy is stored in the body. By means of systems of levers and gears this stored energy may be made to do useful work.

Procedure:

Fasten the spiral spring to the top support. See Fig. 157. At the lower end of the spring, attach a weight hanger so that its pointer will be easily read on the meter stick. Add enough weight to slightly stretch the spring and read the position of the pointer, then place a 200g. weight on the weight holder and read again. Record all readings obtained, in Table XXXIII. Continue adding weights, 200 g. at a time until 800 grams, have been added. Now remove the weights 200 g. at a time, reading the pointer each time a weight is removed. Complete the calculations for which space is provided.

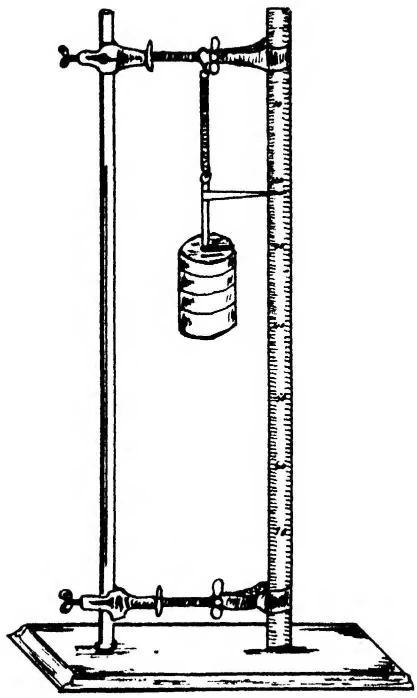

FIG. 157. ELASTICITY OF A SPRING.

Trial	*Stress (Wt.)*	*Reading of Pointer*		*Total Strain (Stretch)*	*Strain per 100 g.*
		Loading	*Unloading*		
Start	Pan				
1	200				
2	400				
3	600				
4	800				

TABLE XXXIII

Make a stress-strain graph on cross-section paper, showing the relationship you have found between the weight (stress) and the stretch (strain) of a spring. Plot the stress as ordinates (vertical axis), and the strains as abscissas (horizontal axis). Make the graph large enough to cover the entire paper.

Questions:

1. When the weight on the spring is doubled (200 to 400, for example) the amount the spring stretched is (cut in half, doubled) ....

....

2. This mathematical relationship is known as a(n) (inverse, direct) .... proportion.
3. From your results, the stresses are found to be (directly, inversely) .... proportional to the strain.
4. State Hooke's Law ....
5. How does a spring balance make use of Hooke's law? ....
6. A spiral spring stretches four inches when loaded with a 2 lb. weight. How much would it lengthen with a four pound weight?

7. How much would it lengthen with a $1\frac{1}{2}$ lb. weight?

8. What weight would lengthen it 6″?

Part B.— Bending

Tools and Materials:

Two metal rods 110 cm.	Dry cell battery
Two knife edge clamps	Slotted weights
Micrometer screw	Weight hangers
Buzzer	Meter stick

Introduction:

In walking a plank or girder you have noticed that the extent of its bending varies according to your weight, your position on the plank, the size and shape of the plank, and the kind of material from which it is made. Engineers, in planning construction work of all types, make use of their knowledge of the strength and properties of materials. The "factor of safety" provides for several times the load expected to be carried due to pressures caused by high winds, floods, etc.

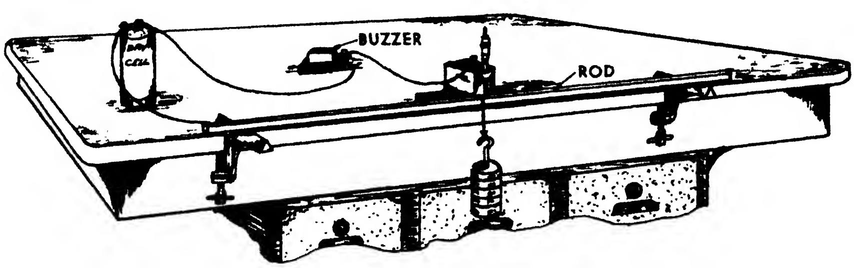

FIG. 158. BENDING OF A ROD.

Procedure:

Fasten two knife edge clamps on the edge of the table so that they will be exactly 100 cm. apart. Place the rod on the knife edges and put the micrometer screw in the exact center, connecting it with a dry cell and buzzer so that the buzzer will sound when the rod and screw are in contact. See Fig. 158. Place the weight hanger in the center of the rod and adjust the screw until it just makes contact. Read the micrometer. Now place a 100 g. weight on the hanger, readjust the screw until contact is made and read the micrometer. Continue adding 100 g. weights until 500 g. is placed on the rod. In order to check your readings remove the weights 100 g. at a time and take each micrometer reading accurately. Record all data in Table XXXIV.

RECORD

Kind of Rod	*Size*		*Area Cross Section*
	Micrometer Readings		
Load	*Loading*	*Unloading*	*Bend*

TABLE XXXIV

Repeat the above experiment, making the distance 50 cm. between supports. Record the information in Table XXXV.

Kind of Rod	*Size*		*Area Cross Section*
	Micrometer Readings		
Load	*Loading*	*Unloading*	*Bend*

TABLE XXXV

Repeat the experiment, using a rod exactly double in width (100 cm. in length). Place its widest edge upon the knife edge. Record information in Table XXXVI.

Kind of Rod	*Size*		*Area Cross Section*
	Micrometer Readings		
Load	*Loading*	*Unloading*	*Bend*

TABLE XXXVI

Repeat the experiment, using a rod exactly double in thickness (100 cm. in length). Place its narrow edge on the knife edges. Record results in Table XXXVII.

Kind of Rod	*Size*		*Area Cross Section*
	Micrometer Readings		
Load	*Loading*	*Unloading*	*Bend*

TABLE XXXVII

Compare Tables XXXIV and XXXV. Notice that when the length of the rod is cut in half the bend is only $\frac{1}{8}$ as much. BEND VARIES AS THE CUBE OF THE LENGTH: $(\text{length})^3$.

Compare Tables XXXIV and XXXVI. Notice that when the width of a rod is doubled the amount of bend is only $\frac{1}{2}$ as much BEND VARIES AS THE RECIPROCAL OF THE WIDTH: $\frac{1}{\text{width}}$

Compare Tables XXXIV and XXXVII. Notice that when the thickness of a rod is doubled the amount of bend is only $\frac{1}{8}$ as much. BEND VARIES AS THE RECIPROCAL OF THE THICKNESS CUBED: $\frac{1}{\text{Thickness}^3}$

From the preceding observations, it will be noted that a given bar will have a variable strength depending upon the way that it is placed upon its supports. A plank for example possesses greater strength if placed edgewise on its supports, as the joists of a house are placed. Mathematically the formula for bending may be expresed as

$$\text{Bending factor} = \frac{\text{length}^3}{\text{width} \times \text{thickness}^3}$$

The strength of a beam, while not measured by the bending factor formula, is dependent upon the same dimensions. The strength of a beam is found by using the formula —

$$\text{Strength factor} = \frac{\text{Width} \times \text{thickness}^3}{\text{length}}$$

Questions and Problems:

1. What part of a steel girder supporting a roof is under "tension" and what part is under compression?

   ....

   ....

2. A small I beam was found to bend as follows when loaded.

Load (lb)	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
Bend (in)	.05	.10	.15	.21	.25	.29	.35	.41	.46	.52	.59	.65	.73	.80	.89

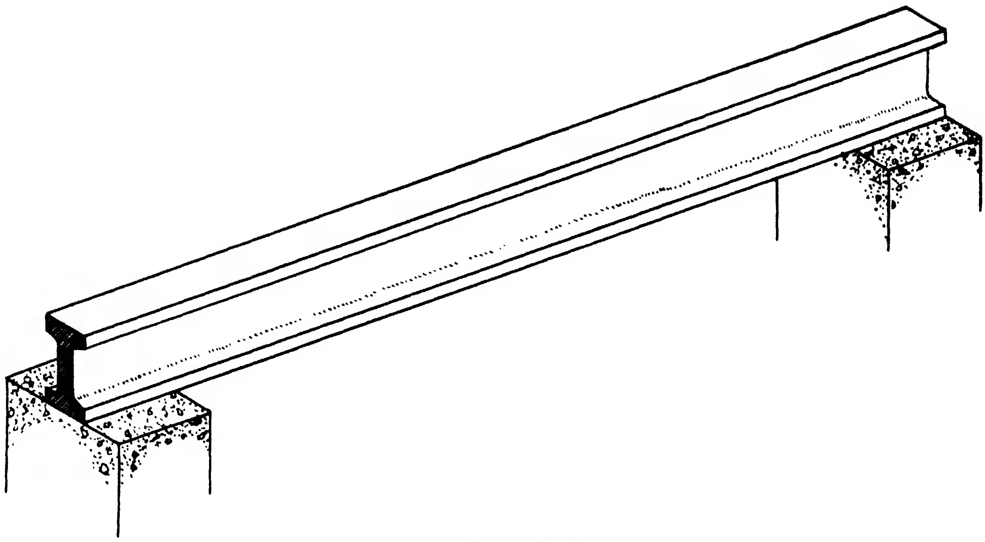

FIG. 159. I-BEAM.

Plot these values on a piece of cross section paper.

Was the elastic limit of the beam exceeded?

Reason for your answer. ....

....

....

3. From your observations, how does the bending of a rod decrease when the length is cut in half? ....

....

When width is doubled? ....

When thickness is doubled? ....

4. A piece of lumber supported horizontally, was broken when a weight of 1800 lbs. was gradually placed midway between supports, which were 10 feet apart. A similar piece broke with a 1200 lb. weight, when the supports were 15 feet apart.

a) (Choose the correct answer). The force required to break a horizontal beam is (directly, inversely) .... proportional to the distance between the supports.

b) What weight would be required to break the above plank if the supports are 12 feet apart?

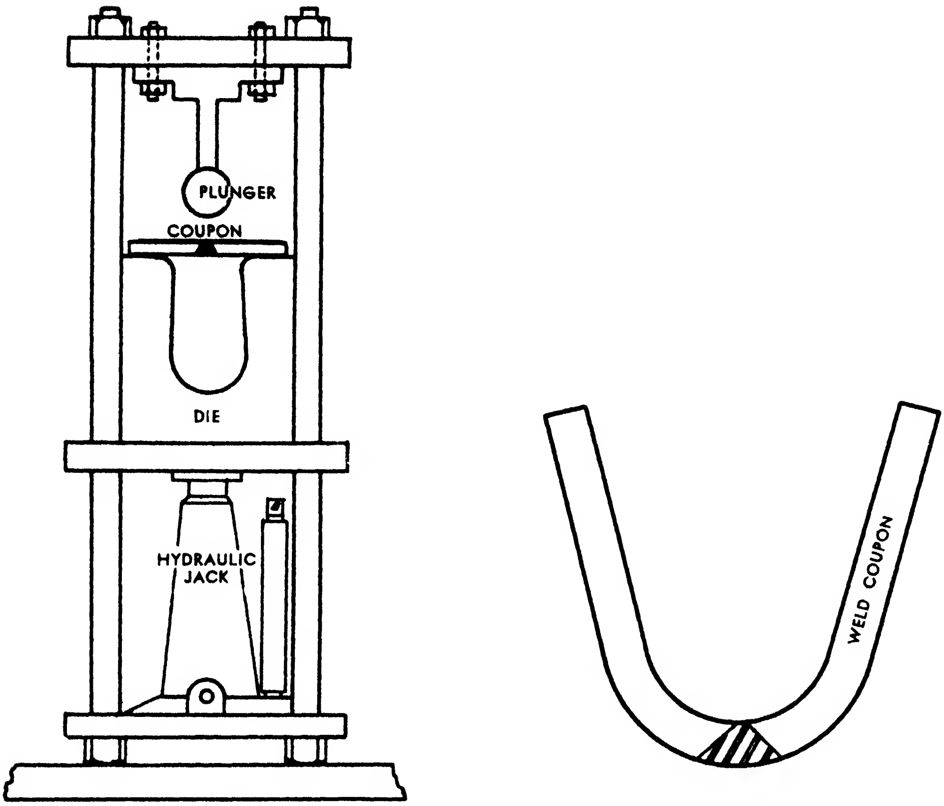

FIG. 160.

5. Fig. 160A shows a "Guided Bend Test Machine" for testing ductility of a weld coupon. Fig. 160B shows the coupon after being bent into a "U" by this machine. Label Fig. 160B, showing the part of the coupon under "tension" and the part under "compression."
6. To save a few dollars, contractors sometime use 2″ x 8″ material for floor joists when 2″ x 10″ pieces should be used. If the span of the joist (distance between supports) is 12 feet, how much more will the 2 x 8 bend than the 2 x 10 when subjected to the same weight.

   (Note — use the formula for Bending Factor when solving.)

Part C.— Torsion.

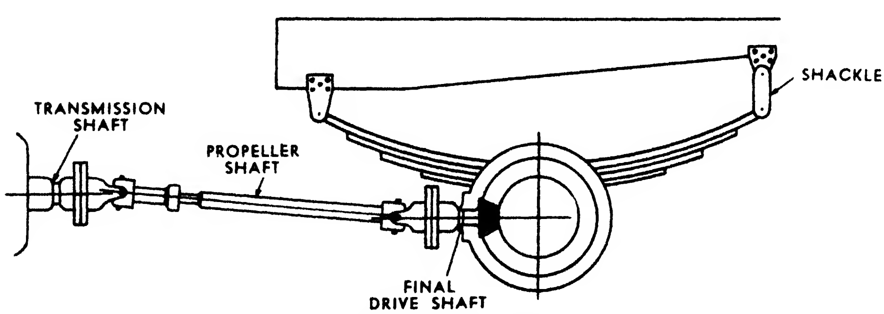

FIG. 161. AUTOMOBILE DRIVE SHAFT.

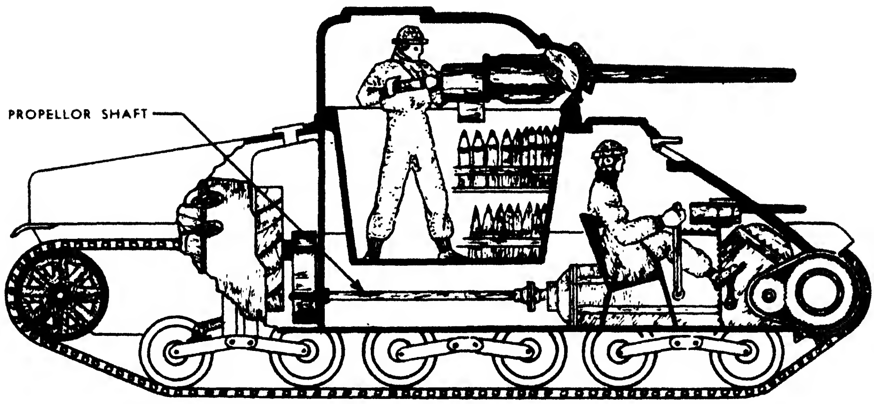

FIG. 162. TANK DRIVE SHAFT.

Introduction:

Examples of twisting stresses are common. They are found in the drive shaft (See Figs. 161 and 162) and rear axle of the automobile, or the power pulley shaft in the shop. Torque is a term often used in rating the motors of trucks and automobiles. Torque is found by multiplying the weight (or force) by the radius of the circle (wheel) on which it operates. Thus, 1 g. acting at the distance of 1 cm. exerts a torque of 1 centimeter gram, or one pound acting at a radius of one foot exerts a torque of one pound foot.

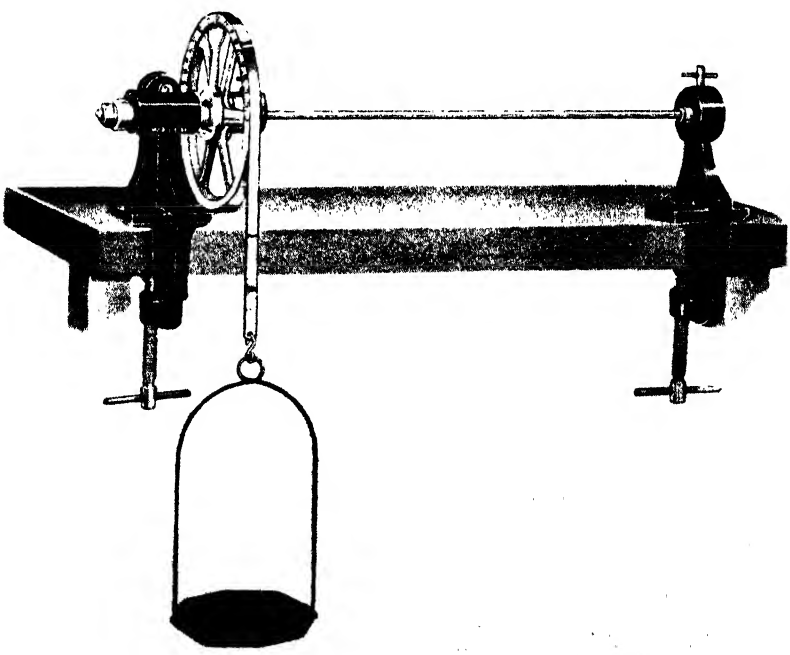

FIG. 163. TORSION APPARATUS. (Courtesy, W. M. Welch Scientific Co.)

Tools and Materials:

Torsion apparatus (may be improvised)
Weights
Various metal rods

Procedure:

Clamp the torsion apparatus, shown in Fig. 163, securely on the table. When the weight pan is in place adjust the vernier so that its zero coincides exactly with the zero of the circular protractor scale. Add 100 g. weight and read the amount of rotation on the vernier scale. Now increase the weight 100 g. at a time and record the reading in Table XXXVIII.

Kind of rod .... Length........................

Round .... Square .... Diameter .... Width ....

Thickness ....

Weight	*Radius wheel*	*Torque (stress)*	*Rotation (strain)*	*Rotation per 100 grams*
100				
200				
300				
400				
500				
600				
700				
800				
900				
1000				

TABLE XXXVIII

Make a graph of the stress-strain relationship on a piece of cross section paper, using data found in Table XXXVIII.

Questions and Problems:

1. Does Hooke's law apply to twisting stresses?

   ....

2. What is meant by "torque"? ....

   ....

3. If the wheel of a torsion apparatus is 10 inches in diameter and a force of 6 pounds applied at the rim, twists the rod through 5 degrees, what force will it require to twist the same rod with a 15 inch wheel through 8 degrees? Show calculations.

4. What torque will be exerted by an 18 inch pipe wrench on a pipe, if a force of 25 pounds is applied on the end of the wrench?

Part D. — Tensile Strength.

Tools and Materials:

Wire breaking apparatus
Micrometer caliper
Various kinds of wire

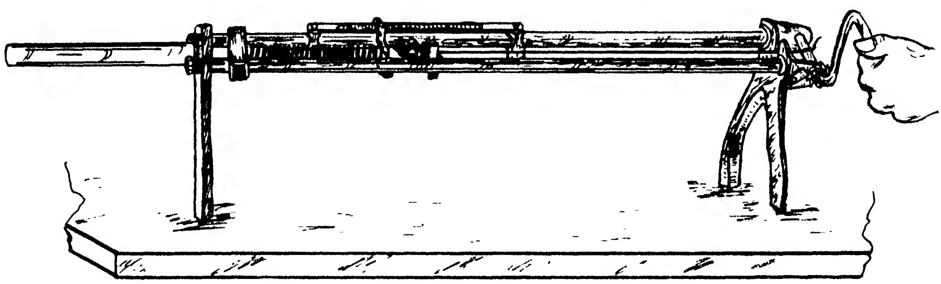

FIG. 164. WIRE BREAKING APPARATUS.

Procedure:

Fasten wire securely at both ends in the apparatus for breaking wire. (See Fig. 164.) See that the gage marker is set at zero and that the pawl on the ratchet wheel is set so that the crank can be turned forward only. Turn the crank slowly until the wire breaks. Read the scale indicating the force required to break the wire. Make two trials so as to check your work. Measure the diameter of the wire accurately (before stretching) with a micrometer caliper. Calculate the area of cross section of the wire; also calculate the ultimate strength of the wire in pounds per square inch (PSI).

$$\text{Tensile strength} = \frac{\text{Breaking force}}{\text{Cross sectional area}}$$

RECORD

Kind of wire .... B & S (or W & M) Gage No. ....

Diameter (inches) .... Cross-sectional area ....

BREAKING STRENGTH: PSI calculations

1st trial ....

2nd trial ....

3rd trial ....

Average ....

Kind of wire .... B & S (or W & M) Gage No. ....

Diameter (inches) .... Cross-sectional area ....

BREAKING STRENGTH: PSI calculations

1st trial ....

2nd trial ....

3rd trial ....

Average ....

Kind of wire .... B & S (or W & M) Gage No. ....

Diameter (inches) .... Cross-sectional area ....

BREAKING STRENGTH: PSI calculations

1st trial ....

2nd trial ....

3rd trial ....

Average ....

Questions and Problems:

1. A piece of copper wire .040″ in diameter, breaks under a load of 85 lbs. Calculate its tensile strength. (PSI)

2. A bar of steel is to be subjected to a force of 60,000 lbs. and is to be designed so that the pull should not exceed 15,000 PSI. What cross-sectional area should it have? If round, what would its diameter be?

3. Name five kinds of stresses.

   a) .... *d)* ....

   b) .... *e)* ....

   c) ....

4. A .... load tends to pull the molecules of a substance apart; a .... load causes the molecules to slide over each other.

5. Steels contain from .05% to 1.7% carbon. Table XXXIX shows the PSI of different types of steels.

Type	*Percent Carbon*	*PSI*
Very mild	.05 — .15	40 — 48,000
Mild	.15 — .25	48 — 60,000
Low Carbon	.25 — .40	60 — 70,000
Medium Carbon	.40 — .60	70 — 80,000
Higher Carbon	.60 — .70	80 — 94,000
Spring	.70 — .80	94 — 108,000
Pearlitic	.85	120,000
High Carbon	1.00 — 1.10	115 — 110,000
Very High Carbon	1.10 — 1.70	100 — 90,000

TABLE XXXIX

Examine the table carefully, then state what effect the percentage of carbon in steel has on the tensile strength of the steel.

....

....

6. What is meant by:

Factor of safety? ....

....

Ultimate strength? ....

....

Elastic limit? ....

....

Stress? ....

....

Strain? ....

....

SPRINGS

Springs, made of special alloys, are used to absorb many of the bumps that would otherwise be transmitted from the uneven highway to the passengers riding in a car. The alloys usually used are silicon steel or chrome vanadium steel, these having been developed with a high elastic limit.

The two types of springs most commonly used today are the leaf spring of the semi-elliptic type, (Fig. 165) and the coil spring, (Fig. 166). With the perfection of better spring steels, semi-elliptic springs are comparatively flat or straight today as compared to the highly cambered or curved springs of a

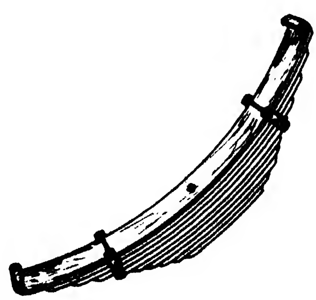

FIG. 165. SEMI-ELLIPTICAL SPRING.

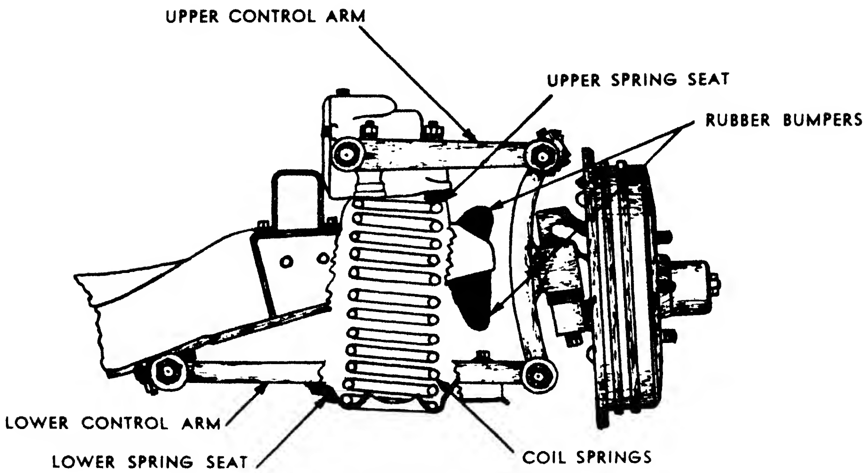

FIG. 166. A COIL SPRING.

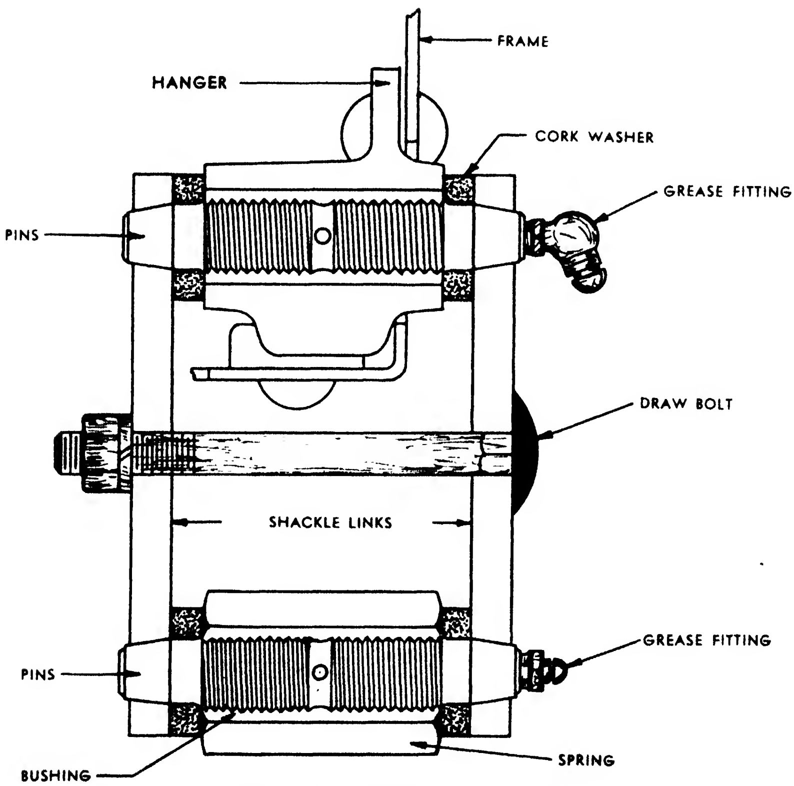

FIG. 167. A SPRING SHACKLE.

few years ago. They have also been made longer and more flexible for greater riding comfort. The coil spring has several advantages over the leaf spring, and some disadvantages. One of its advantages is that it does

not need lubrication, because it is practically frictionless. It also makes a smoother riding car because it is active throughout it's entire length. However, to control the action of a coil spring and to prevent the wheels from moving forward, backward or sideways during driving and stopping, shock absorbers, stabilizers and torque members must be used. Since the leaf type spring changes its length as the weight of the car moves up and down, the ends are made free to move by mounting them to the frame with a spring shackle, Fig. 167.

Rubber bumpers are used in connection with both types of springs. See Figs. 166 and 168. These act as auxiliary springs and are expected to come into action when carrying slight overloads.

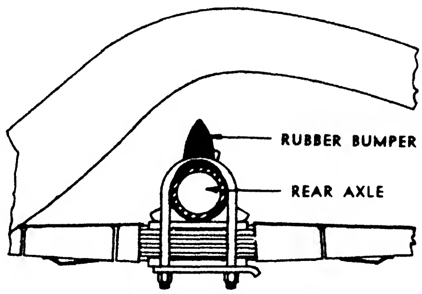

FIG. 168. RUBBER SPRING BUMPERS.

VISCOSITY

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 152-160.
Dull: *Modern Physics*, pages 89-105.
Fletcher: *Unified Physics*, pages 19-24.
Holley and Lohr: *Mastery Units in Physics*, pages 19-60.
Millikan: *New Elementary Physics*, pages 131-146.
TM 540 *Automotive Lubrication*, pages 1-47.
TM 10-570 *Internal Combustion Engine*, page 75-102.
Texas Company: *Diesel Operation, Fuel and Lubricants.*
Sun Oil Company: *Lubrication of Industrial Machinery.*

VISCOSITY

Cohesion is the mutual attraction that holds the particles of any substance together. The molecules of a fluid have a tendency to roll over one another with out losing cohesive contact. Liquids have the ability to flow and change their shape, hence are known as fluids.

Molecules of a liquid are held together by a force called molecular attraction. This force causes a resistance to the motion of one molecule over another. Resistance to flow, or internal cohesiveness, is known as *viscosity.*

It is generally known that molasses flows with greater difficulty than water. This is due to the fact that molasses has a greater viscosity than water; the molecules of molasses have greater difficulty in rolling over each other than those in water. Viscosity changes with temperature.

MEASURING VISCOSITY

The Society of Automotive Engineers (S.A.E.) has devised a method

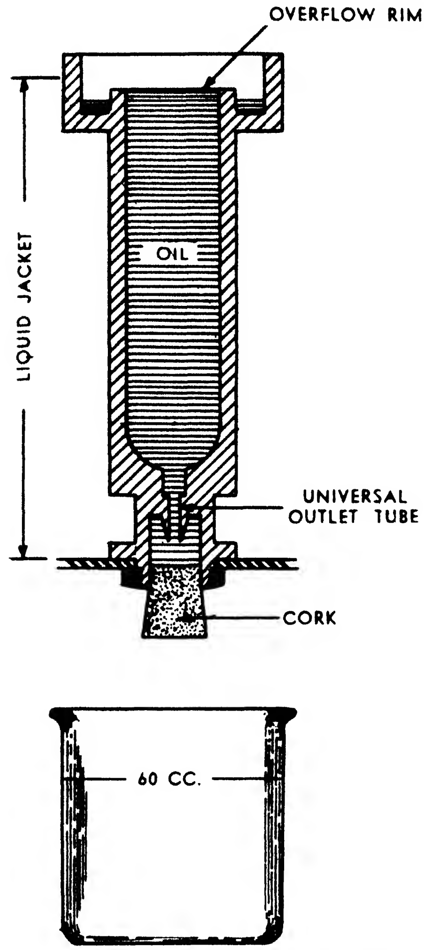

FIG. 169. VISCOSITY METER.

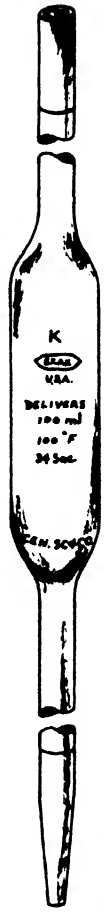

FIG. 170. PIPETTE.

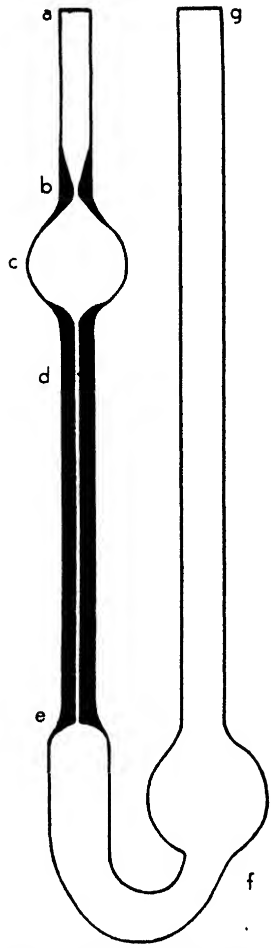

FIG. 171. OSTWALD VISCOSITY PIPETTE.

for classifying lubricating oil according to its viscosity. The Saybolt Universal Viscosimeter, Fig. 169, is used in making this classification. The method consists in timing the flow of two ounces of oil from an outlet tube of $\frac{1}{16}''$ diameter while the temperature is held constant. The S. A. E. numbers by which oil is designated and their corresponding Navy symbols are given in Table XL.

S.A.E. No.	*Navy Symbol*	*Saybolt Viscosity — seconds* at 130°F (54°C)	*Saybolt Viscosity — seconds* at 210°F (99°C)
10	2110	90 — 120	
20	3050	120 — 185	
30	3065	185 — 255	
40	3080	255 —	— 80
50	3100		80 — 105
60	3120		105 — 125
70	3150		125 — 150

TABLE XL

Since viscosity is generally conceded to be the most important property of a lubricating oil, different oils are recommended to meet varying operating conditions. These conditions include air temperatures, operating temperatures of the engine, and the age of the engine. An engine requiring S.A.E. 30 or 40 oil in summer or in mild climates would require an S.A.E. 20 or 20W oil in winter or in cold climates. Liquid cooled engines require lighter oils than air cooled engines under the same operating conditions. It is considered good practice to break-in a new engine with the lightest oil possible without causing excessive oil consumption.

The second common method for measuring viscosity is the pipette method. This consists in observing the time required for a number of drops of oil to fall from a clean pipette. (See Fig. 170.) Comparison between the viscosities of oils can me made by this method.

A third method frequently used in laboratories involves the Ostwald viscosity pipette. (See Fig. 171.) In this method, the viscosity is measured by comparing the time required for a sample of oil and a sample of water to flow through a capillary tube, both liquids being at the same temperature.

MEASURING VISCOSITY OF MOTOR OIL

Purpose:

1. To compare the viscosities of several motor oils.
2. To study the effect of temperature on viscosity.

Tools and Materials:

Piece of glass tubing 3 ft. long
250 cc. graduate
Battery jar
Thermometer
Ball bearing
Motor oils (various S. A. E. Nos.)
Ostwald viscosity meter (not necessary)

Procedure:

The viscosity of oils may be compared by one or more of the following methods.

a) Select three grades of motor oil, for example S. A. E. 10, 30 and 50. Take the temperature of the oils, making sure it is the same for all. Correct the temperatures, if necessary, by heating and cooling. Fill a 250 cc. graduate with S. A. E. 10 motor oil. Drop a ball bearing in the oil and time its descent to the bottom by means of a stop watch. Repeat with other grades of oil and record results in Table XLI. Repeat with the oil at a higher temperature.

	Time at Temp. °C		*Time at Temp. °C*		*Time at Temp. °C*	
S.A.E. No.	*Bearing*	*Bubble*	*Bearing*	*Bubble*	*Bearing*	*Bubble*
10						
20						
30						
40						
50						
60						

TABLE XLI

b) An alternate method is to time the rise of a bubble through a quantity of oil. Fill a glass tube (sealed at one end) with a sample of oil to within one quarter of an inch of the top. Place the finger over the open end of the tube and turn it upside down. By means of a stop watch, determine the length of time necessary for the bubble of air to reach the top. Repeat with other grades of oil. Record in Table XLI. Compare the time for a bubble to rise, or a ball bearing to fall, with the S.A.E. number of the oils used. How does this time act as a measure of viscosity? How does temperature affect viscosity?

c) An Ostwald Viscosimeter is a very accurate means of measuring viscosity of oils. See Fig. 169. A known amount of oil is placed in the right hand side arm at (g) and is pulled up by suction into the left hand side at (a) until the level is above (c). With a stop watch, the time necessary for the liquid to flow back from (b) to (d) through the capillary tube (dc) is determined. The time required is compared with the time taken for water to flow through the tube. The viscosity of the oils is compared with water, as a standard liquid having a viscosity of 1.

The temperature of the viscosimeter is kept constant by suspending it in a constant temperature water bath. This experiment is best done by the instructor as a demonstration.

Questions and Problems:

1. Define the term viscosity. ....

....

2. Give some examples of liquids with a high viscosity. ....

....

3. Explain how viscosity varies with temperature. ....

....

....

4. Why is it necessary to use a different S. A. E. oil in an automobile engine in winter than in the summer? ....

5. Explain how the viscosity of oil affects the operating efficiency of a motor. ....

....

....

SURFACE TENSION

Molecular attraction at the surface of a liquid causes it to possess a property known as surface tension. Here, molecules are being pulled inward toward the body of the liquid. This inward attraction of molecules causes the surface area to shrink and possess a tension acting like a tight film drawn over the surface of the liquid.

The surface tension of water may be demonstrated by floating a needle or a razor blade on its surface.

Soap bubbles are effective in demonstrating surface tension. Blow a soap bubble, with a pipe or glass funnel, to about the size of a base ball. Remove the pipe from the lips and the soap film will force the air out of the bubble as if it were a rubber balloon.

Oils have less surface tension than water. When oil is poured on water, it spreads over the water forming a thin film. The smaller the surface tension of the oil, the greater will be its tendency to spread over the surface of other liquids or solids.

This property of oil which causes it to spread in a thin film over solids, is most important in the lubrication of machinery. Oil spreads over metal surfaces as it does over water. An oil film is absorbed by a metallic surface. Two metal surfaces covered by a film of oil are held apart by that film when the two are rubbed together. This film reduces the friction between two surfaces by simply holding them apart a few thousandths of an inch.

CAPILLARY ACTION

As has been stated in a previous section, liquids have a tendency to spread over surfaces that they touch in proportion to their viscosity. Oil is drawn into the space between a piston and the cylinder wall by capillary action. A coolant flows between a machine tool and the stock it is cutting by capillary action. "Penetrating" oil spreads between the leaves of an automobile spring by capillary action.

Capillary action may be demonstrated by dipping tubes of small bore into colored water and observing the height to which the water climbs. See Fig. 172. This climbing action is due to adhesion and surface tension. Adhesion raises the edges of the water touching the tube. Surface tension tends to draw the surface of the water flat. These two actions lift the water until the weight of the column of water counterbalances the forces of adhesion and surface tension.

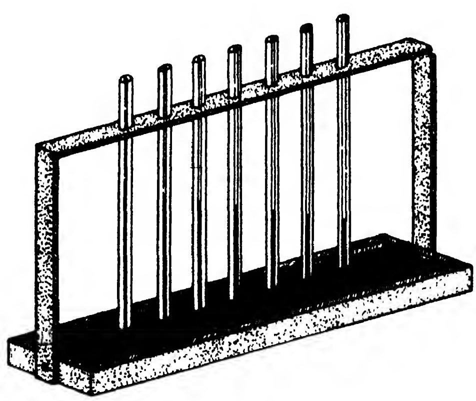

FIG. 172. CAPILLARY TUBES.

It will be seen from the foregoing discussion and demonstration that the smaller the diameter of the hole (bore) in the tube the higher the water will climb within the tube. Oil spreads as a film in the clearance between a bearing and a shaft, no matter how small, in much the same manner as water climbs in a capillary tube. Films as thin as one millionth of an inch have been measured. Theoretically, a film of oil may spread out until it is but one molecule in thickness. Capillary action, therefore,

is partly responsible for the efficient lubrication of moving parts of machinery.

LUBRICATION

The invention of the wheel and axle brought about the need for a knowledge of lubrication. The earliest record we have of lubrication, is the use of mutton tallow on the axles of chariots about 1500 B. C. Herodotus wrote a technical description of oils and greases in use at that time. Sir Isaac Newton laid the foundation for modern lubrication when he propounded the theory that lubrication was a mechanical action and therefore was controlled by the laws of motion (the student should refer to Newton's three laws of motion). Newton concluded that between two lubricated, moving bodies, the resisting force per unit area is proportional to the velocity divided by the distance between the two surfaces. The constant of this proportional equation is the "viscosity constant."

In the latter part of the nineteenth century it was discovered that a journal turning in a lubricated bearing, built up an exceedingly high pressure within the lubricant. This discovery led to the formation of the oil wedge theory of lubrication by Osborne Reynolds. Reynolds found that as a shaft rotates in a bearing or as one body slides over another with a lubricant present, that the film of oil between them is not of uniform thickness, but in the shape of a wedge. (See Fig. 173.) A lubricant adheres

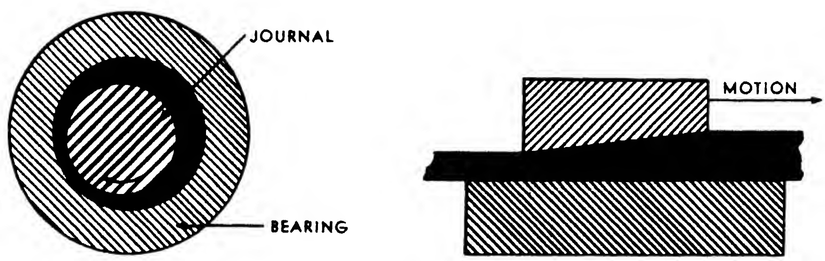

FIG. 173. THE OIL WEDGE.

to a bearing surface, and is also partially absorbed by the surface. The oil itself is held together by the cohesive action of its molecules. (Fig. 174.) When a journal turns or a body slides over another, the oil adheres to both the moving and stationary body. A pressure is built up in the oil between the bearing surfaces and it is this pressure that supports and floats the moving body, preventing actual contact between moving parts. (See Fig. 175.)

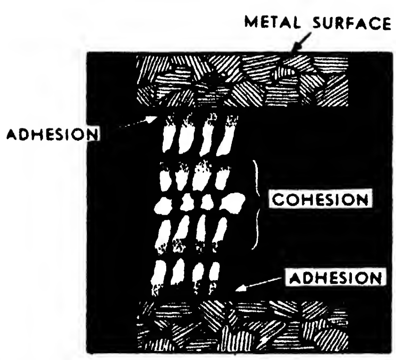

FIG. 174. COHESION AND ADHESION.

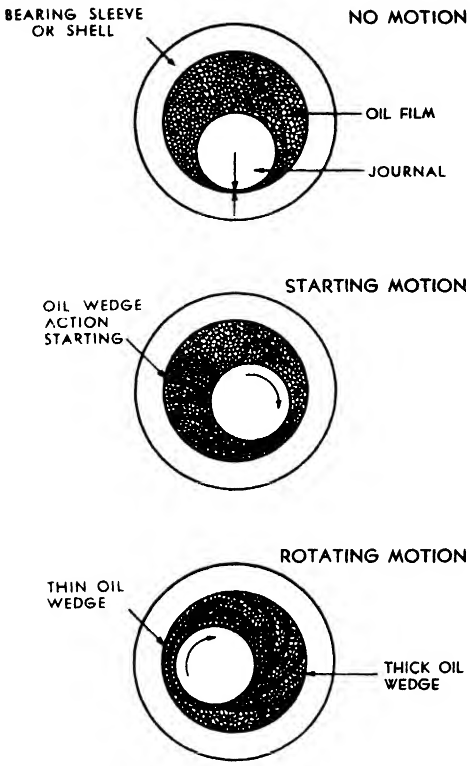

FIG. 175. OIL WEDGE.

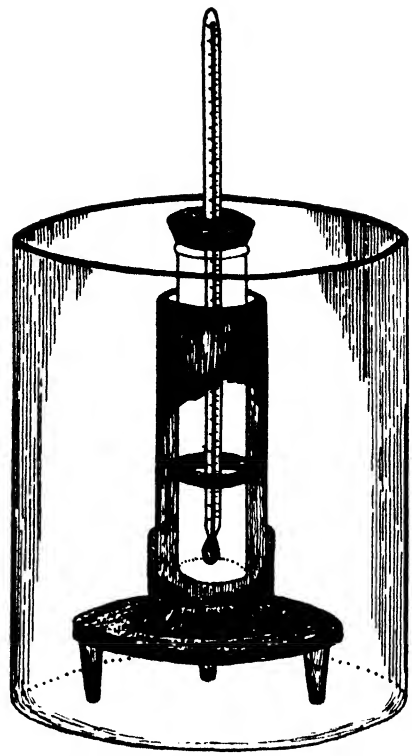

FIG. 176. POUR POINT APPARATUS.

The molecules of the oil must hold together and not rupture as pressures build up between bearing surfaces or when friction develops high temperature. Rupture of the oil film would mean metallic contact between bearing surfaces and therefore excessive wear or possible damage to the surfaces would result. The viscosity of the oil must be sufficient to keep the bearing surfaces apart.

FACTORS AFFECTING LUBRICATION

The chief factors affecting lubrication are speed, pressure and temperature. Speed affects lubrication by building up a pressure between rubbing bodies and forming a floating film. At very low speeds this floating film may not be formed and friction between bodies may become excessive. The use of heavy greases, graphite, and solid lubricants will prevent excessive friction at low speeds.

Heavy lubricants will also prevent high bearing loads from pressing out the lubricant. The pressure of the bearing load must not be allowed to rupture the oil film. With an increased bearing load, the viscosity of the oil used must be higher.

The friction between bearing surfaces develops a certain amount of heat which raises the temperature of the lubricant and reduces its viscosity. The viscosity may be reduced to the point where the oil is incapable of separating bearing surfaces. When this takes place, excessive heat and

wear occur. Sticky gum and varnish may be formed if too high a temperature is reached.

LUBRICATING TEMPERATURES	
Operating Conditions	*Temperature*
Crankcase (summer)	200°F — 250°F
Crankcase (winter)	90°F — 110°F
Cylinder walls (water cooled gas engine)	200°F — 300°F
Cylinder walls (air cooled engine)	300° — up
Bearings (plain)	90° — 120°
Crankshaft and Camshaft	200° — up

TABLE XLII

At very low temperatures the viscosity may become so great that excessive friction is built up within the lubricating body. For example, in freezing weather an engine's lubricant may become so heavy that it is difficult for the starter to turn the engine. Oil of proper viscosity should be selected according to expected temperatures. See Table XLIII.

Temperature expected		*Grade*
Summer Temperature	90°F	20 — 30 S. A. E.
Not lower than	32°F	20 or 20W
Low as	10°F	20W
Low as	0°F	10W
Below	-10°F	10W + 10% Kerosene

TABLE XLIII

POUR POINT

The pour test is used to determine the ability of the oil to flow at low temperatures. A sample of oil is chilled in a cooling solution and at each 5° drop in temperature the sample is tilted to observe the flow of oil. The pour point is 5° higher than the point where the oil ceased to flow. (Fig. 176.)

ADDITIONAL FACTORS AFFECTING LUBRICATION

Oil from the crankcase of a motor car should be drained and fresh oil added every 2000 - 5000 miles of operation. This is necessary because any accumulation of foreign substances will contaminate the oil. In spite of every possible precaution in caring for the modern motor, a certain amount of dust, dirt, carbon, water, and gasoline will get into the oil, thereby reducing the oil's effectiveness. Dust and dirt may act as an abrasive, scratching and scoring bearings and cylinder walls. Water may freeze and interfere with circulation of oil.

Crankcase dilution may become serious if leaky piston rings allow exhaust gases to carry some water vapor and gasoline into the lubricating oil. Raw fuels contain small amounts of sulphur and other substances that form oxides when burned. These oxides dissolve in and combine with water to form acids and corrosive substances which cause etching, pitting,

and corrosion of all moving parts. Great engineering skill is used in designing motors to prevent contamination of lubricating oil.

The purpose of a good oil is to reduce friction and wear on bearing surfaces. A good lubricating oil:

1. Prevents scratching
2. Has no corrosive action on bearings
3. Acts as a coolant
4. Is free from sludge
5. Has low viscosity change due to temperature
6. Has correct fire and flash points
7. Has proper pour qualities at low temperature
8. Resists rupture of oil film.

LUBRICATING SYSTEM FOR INTERNAL COMBUSTION ENGINES

Friction lowers the efficiency and increases wear in all engines. To eliminate friction as much as possible, all engines are designed so that their moving parts are constantly covered with a film of lubricating oil. This film of oil "floats" the moving parts, preventing metal to metal contact, thus minimizing the heat and wear produced by friction. To further reduce the temperature of the engine, the oil is cooled by a draft of air over the oil in the "oil pan" or by passing the oil through a tubular oil cooler.

Engines may be lubricated by the splash system or by "force feed." Fig. 177 illustrates a typical force feed lubricating system by which oil is pumped to all the major moving parts by means of a gear type oil pump, Fig. 178, through a system of rifle drilled passages.

All oil from the pump is first forced through the oil filter. This filter is provided with safety valves for by-passing the oil around the filter

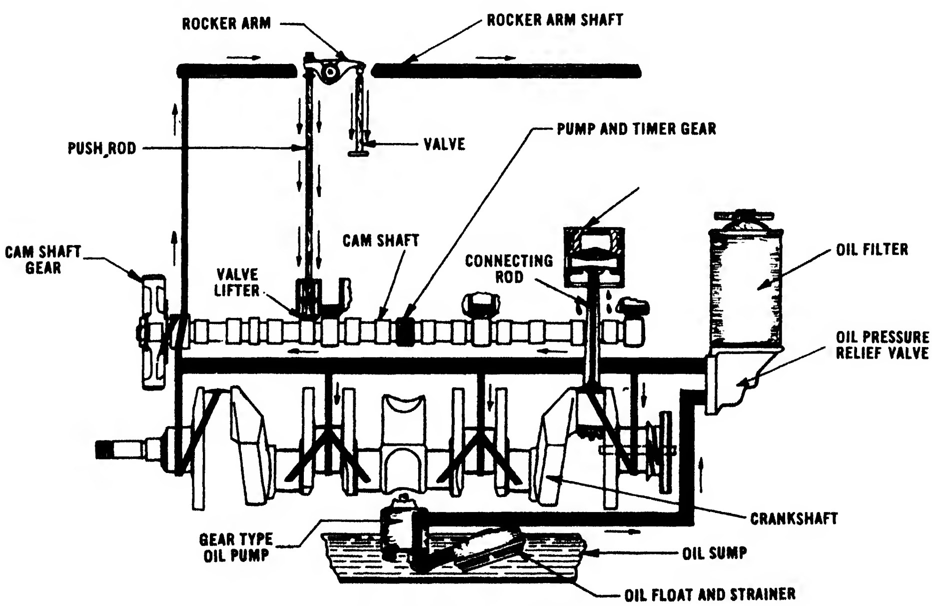

FIG. 177. FORCE FEED LUBRICATION

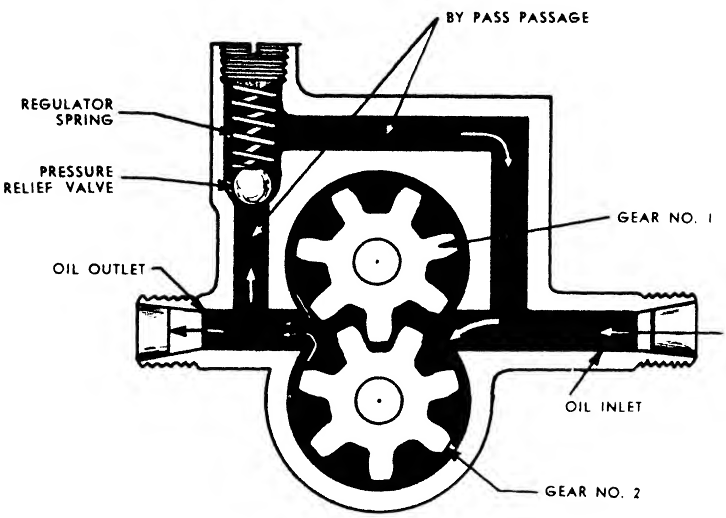

FIG. 178. OIL PUMP.

if the filter becomes clogged or if the oil builds up a too high line pressure due to high viscosity in severely cold weather.

After the oil passes through the filter, it is pumped through a drilled passage and drilled holes in the crankcase webs, to the main and camshaft bearings. Drilled passages in the crankshaft and connecting rods carry oil to the connecting rod and piston-pin bearings. Oil thrown from these bearings lubricates the cylinder walls.

A flat surface milled on the front camshaft bearing journal, intermittently registers with a drilled passage leading up through the cylinder head and front rocker arm bracket to the hollow rocker arm shaft, providing an intermittent flow of oil to the valve mechanism.

A valve oiler pad over the rocker arms is kept saturated with oil from drilled holes in the top of the rocker arms. It assists in providing ample lubrication to push rod balls and sockets at one end of the rocker arms and valve stems at the other end. Overflow oil from the valve mechanism returns to the crankcase through valve lifter rod holes in the cylinder head and crankcase, lubricating the valve tappets on the way down.

The timing gears are lubricated by oil forced through three drilled passages in the idler gear shaft which registers with a drilled hole to the idler gear teeth and deliver three charges of oil to the gear teeth every revolution. This assures ample lubrication to the timing gears.

New Words:

ABSORB.—To take into; to penetrate.

ADSORB.—To adhere to, as a thin film; a molecular film sticking to the surface of a substance.

BEARING.—A surface that supports a load. A surface area which withstands friction due to the sliding or revolving of another body.

CAPILLARY TUBE.—A tube of fine bore, having a small enclosed space.

CLEARANCE.—Space between two adjacent bodies. Space between moving parts.

COOLANT.—Liquid used to reduce heat and friction between bearing surfaces.

DILUTION.—The process of thinning or making more fluid; reducing viscosity.

Etching.—Scarring the surface of a substance by chemical or mechanical action.
Film.—A thin layer of a substance, microscopic in thickness.
Fluid.—A substance (liquid or gas) which flows or moves easily due to pressure.
Intermittent.—Occuring at different times.
Journal.—That portion of an axle, spindle or rotating shaft that rests or turns in a bearing.
Pitted.—Small depressions or cavities in the surface of a smooth substance.
Register.—To coincide exactly.
Rupture.—To part; to break apart or divide.
Scored.—Scratched or dug out in grooves by abrasion.
Sump.—A reservoir at the bottom of the crankcase where oil collects.

Additional New Words:

__________ ....

....

__________ ....

....

__________ ....

....

LUBRICATING OIL TESTS

Purpose:

1. To learn the tests for evaluating oils.
2. To perform simple tests on selected oil samples.

Tools and Materials:

Test tubes (hard glass)
Thermometer (700°F)
Crucible
4 oz. flat side bottle
water bath
Hydrometer
Sheet of polished copper
Salt
Ice

Introduction:

There are many tests used to evaluate the character of lubricating oils. Tests may be made on the common grades of lubricating oil. Comparison tests may be made between a fresh oil and one that has been used in a motor for some time. Results will be only approximately correct unless standard S.A.E. methods and equipment are used.

Procedure:

a) Visible Impurities

Pour a sample of oil into a 4 ounce, flat sided bottle. No visible materials should be seen when examined before a strong light. Try this with a sample of "used" oil. Results ....

....

b) Corrosive Constituents

Measure a 10 ml. sample of fresh oil and a similar sample of used oil, into separate test tubes. Immerse both test tubes of oil in a large beaker

of boiling water. Place in each a strip of newly polished copper so that only a portion of the strip is immersed. Heat for three hours.

Corrosive constituents, such as free or combined sulphur, will effect the copper strip. Withdraw the strips, rinse, and examine for evidence of corrosion. Results ....

....

c) *Specific Gravity* (Consult a handbook for specific gravity of various grades of oil).

The specific gravity of an oil may be measured by several methods. The quickest method is to use the hydrometer method.

Pour samples of oil into hydrometer jars and measure the specific gravity with a universal hydrometer. Record results in Table XLIV.

	SPECIFIC GRAVITY TESTS				
Sample of Oil	*S. A. E. Grade*				
	10	20	30	40	50
Fresh Oil					
Used Sample of same grade					

TABLE XLIV

d) *Flash point - Fire point*

The flash point and the fire point is an important test for motor oil. The flash point is the temperature at which oil will ignite when exposed to a flame but will not continue to burn after the flame is removed. The fire point, which is about 50° higher, is the point at which the oil will burn without the aid of an external flame. The flash point of medium grade engine lubricating oil should be about 500°F., but not below 400°F. A low flash point may cause excessive oil consumption while too high a flash point will cause fouling of spark plugs.

Half fill a crucible with a sample of motor oil. Immerse a thermometer in the oil — avoid touching the bottom. Heat slowly with a bunsen flame. As the temperature approaches 400°F. pass a small flame over the surface of the oil. Note the temperature at which the oil just flashes and again when it burns freely.

Flash point .... Fire point .... S.A.E. Grade ....

e) *Viscosity* — Refer to the discussion on viscosity.

f) *Pour Test*

The pour point is 5°F. above the point at which a sample of oil refuses to pour. Samples of S. A. E. 40, 50, 60 or 70 may be used. Surround test tubes containing oil samples with a mixture of equal parts of coarse salt and cracked ice. Immerse a thermometer into each sample of oil. With each

5° fall of temperature remove and tilt to observe pour action. Record pour temperatures in Table XLV.

S.A.E. Sample	*40*	*50*	*60*	*70*
Standard	0°	5°F	10°F	30°F
Sample				

TABLE XLV

g) Carbon Residue

Burn a sample of oil to observe carbon residue. Compare with a sample of used oil. Results ....

(Other tests may be made if equipment and time is available.)

Questions:

1. The apparent film on the surface of a liqquid is caused by the interattraction of surface molecules, and is known as .... A needle floating on water demonstrates the effect caused by .... A drop of water falling through space assumes a .... shape because of .... The surface tension of oil is (higher, lower) .... than water. The ability of an oil to spread is determined by its degree of ....
2. Newton developed the theory that lubrication was a .... action and therefore controlled by the laws of .... Sir Isaac Newton developed three laws of motion. These are:

   1) ....
   ....

   2) ....
   ....

   3) ....
   ....

   Newton concluded that between two lubricated moving bodies, the resisting .... per unit .... is proportional to the .... divided by the distance between the two surfaces.
3. As one body slides over another, the film of oil between them (is, is not) .... of uniform thickness. The pressure built up within the lubricant .... the moving bodies, preventing metallic ....

4. The three factors affecting lubrication are *1)* ....

   2) .... and *3)* ....

   When the temperature of an oil is increased, the .... is reduced.

5. In a gasoline motor, contamination of oil may be caused by ....

   ....

6. Crankcase dilution is ....

   ....

7. The characteristics of a good motor oil are ....

   ....

   ....

SOLUTIONS AND EMULSIONS

McPherson: *Chemistry at Work,* pages 63-65; 417.
Hopkins: *Chemistry and You,* pages 113-120.
Kruh, Carleton, Carpenter: *Modern Life Chemistry,* pages 135-182.

Introduction:

A solution is a mixture of two or more substances.. The substances in a solution are so finely divided that they are considered to be in the molecular state. This belief is supported by the fact that the particles in a solution cannot be seen, even with the most powerful microscope or separated from each other by means of the finest filter. When salt or sugar dissolves in water, the crystals break apart into the individual molecules and distribute themselves uniformly among the molecules of the water. The salt or sugar disappears from view but can easily be detected by tasting the solution or can be recovered again by simply evaporating the water from the solution.

A solution consists of two parts, namely the *solute* and the *solvent.* The solute is the substance being dissolved while the solvent is the substance in which the solute dissolves. Most people think of solutions as being liquids, but solutions can be solid or gaseous. Petroleum, for example is a solution of liquids in liquids; ginger ale and other carbonated drinks contain carbon dioxide gas dissolved in water; air is a solution of several gases; monel metal is a solid solution of copper in nickel.

Solutions may also be dilute, concentrated, saturated, unsaturated or supersaturated. A *dilute* solution contains a small amount of solute as compared with the quantity of solvent. A *concentrated* solution contains a relatively large amount of solute as compared with the quantity of solvent.

Fig. 179 illustrates the conditions existing when solutions are in different degrees of saturation. At the same temperature a solution which will dissolve more of the same solute is *unsaturated;* if no more solute will

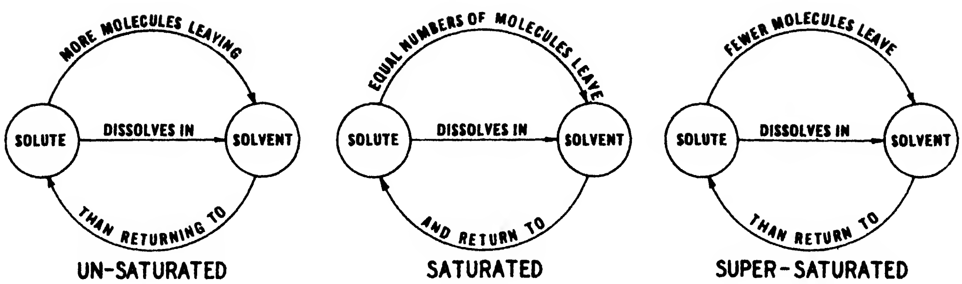

FIG. 179. TYPES OF SOLUTIONS.

dissolve the solution is *saturated*. A *supersaturated* solution is unstable, i. e., a rather unusual substance. It is prepared by carefully cooling a saturated solution. This can be demonstrated better than it can be told.

DEMONSTRATING A SUPER-SATURATED SOLUTION

In a perfectly clean test tube place 10 g. of sodium acetate ($NaC_2H_3O_2$) and 2 cc. of water. Heat gently until every particle of the solute is dissolved. Place the test tube carefully in a beaker of cold water, allowing it to cool to room temperature. If properly done, the sodium acetate will still be in solution (a supersaturated solution). Now drop a tiny crystal of sodium acetate into the solution. The solution will immediately crystallize. Feel the test tube in order to note what happened to its temperature. This action is typical of all super-saturated solutions.

Solubility is controlled by many factors such as the *nature of the solute, nature of the solvent, temperature and pressure*. Water, the universal solvent, will disolve more substances than any other solvent, yet a substance such as oil which will not dissolve in water, will dissolve readily in gasoline, ether, or carbon tetrachloride.

It is generally true that solid solutes will dissolve more rapidly and in greater quantity when the temperature is raised. There are exceptions to this however, the minerals which are precipitated on steam boiler tubes (boiler scale) by the high temperature of the water, being a typical and important exception.

Gases are more soluble in liquids when placed under increased pressure in a cold solvent. This principle is applied in making carbonated beverages and in filling steel cylinders with acetylene gas used for welding. Acetylene gas is explosive when compressed, however it is safely stored by dissolving it in acetone, under pressure. How do you account for the bubbles which rise in a bottle of gingerale when the cap is removed?

When the particles of solute are larger than molecules, other types of solutions result. If the particles are still so small (colloidal) that they will not settle out upon standing, the mixture is known as a colloidal solution. These solutions are usually turbid when viewed in a bright light.

When the particles of solute become so large that they will settle to the bottom, the mixture is known as a *suspension*. Paint is a typical example of a suspension.

When two liquids are insoluble in each other they are said to be "im-

miscible." Two such liquids will break up into fine globules when vigorously shaken together forming a milky looking mixture. These two liquids will separate into distinct layers upon standing for a short time.

Two immiscible liquids can be held in permanent suspension by the addition of a third substance known as an "emulsifying agent." Such a mixture is known as an *emulsion*. The emulsifying agent forms a thin film around the small drops of liquid, decreasing their surface tension so that there is less tendency for the globules to collect together.

New Words:

ACETONE.—A clear liquid, obtained by the destructive distillation of wood, used as a solvent for acetylene gas.

COLLOIDAL.—Extremely small particles of matter.

FILTER.—A device for clearing or purifying liquids by straining.

GLOBULE.—A small drop.

PRECIPITATE.—To cause to separate out as an insoluble substance from a state of solution.

TURBID.—Cloudy or muddy in appearance.

Additional New Words:

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PREPARING SOLUTIONS AND EMULSIONS

Purpose:

1. To observe the conditions which affect solubility.
2. To compare true solutions, collodial solution and suspensions.
3. To make an emulsion.

Tools and Materials:

Coarse rock salt
Chalk
Oil
Flowers of sulphur
Grain alcohol
Soap solution
Mortar and pestle
Filter paper
Funnel

Procedure:

a) Size of solute particles

To see what effect the size of the solute particles will have upon the time required for dissolving, shake 2 g. of coarse rock salt in 15 cc. of cold water. Observe the time required to dissolve the salt. Repeat the test, using salt that has been ground into a fine powder with a mortar and pestle.

The (finer, coarser) .... the solute particles, the less time required for dissolving.

b) Stirring or agitating during solution

Study the effect of agitating a solution by placing 2 g. of powdered salt in each of two test tubes containing 15 cc. of water. Allow one to stand motionless while vigorously shaking the other. The salt in the test tube which was .... dissolved more rapidly.

c) Effect of raising the temperature

Repeat the test made in part (b) by heating one of the test tubes and allowing the other to remain at room temperature. The salt in the (hot, cold) .... water dissolved more rapidly.

d) Suspensions

Place a small quantity of powdered chalk in a test tube $\frac{3}{4}$ full of water. Shake vigorously, then allow to stand motionless for a few minutes.

The mixture of chalk and water is (cloudy, clear) .... and the chalk (does, does not) .... settle out on standing.

e) Colloidal solutions

Shake about 1 g. of powdered sulfur in a test tube $\frac{1}{2}$ full of alcohol. Some of the sulfur will dissolve in the alcohol. Allow the undissolved sulfur to settle, then pour the clear solution into a beaker of water. Since sulfur is not soluble in water, it will precipitate out in collodial form. What is the appearance of a solution of collodial sulfur? ....

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Divide the collodial solution into two parts. Allow one part to stand motionless and filter the other part. Set up the filter as shown in Fig. 180.

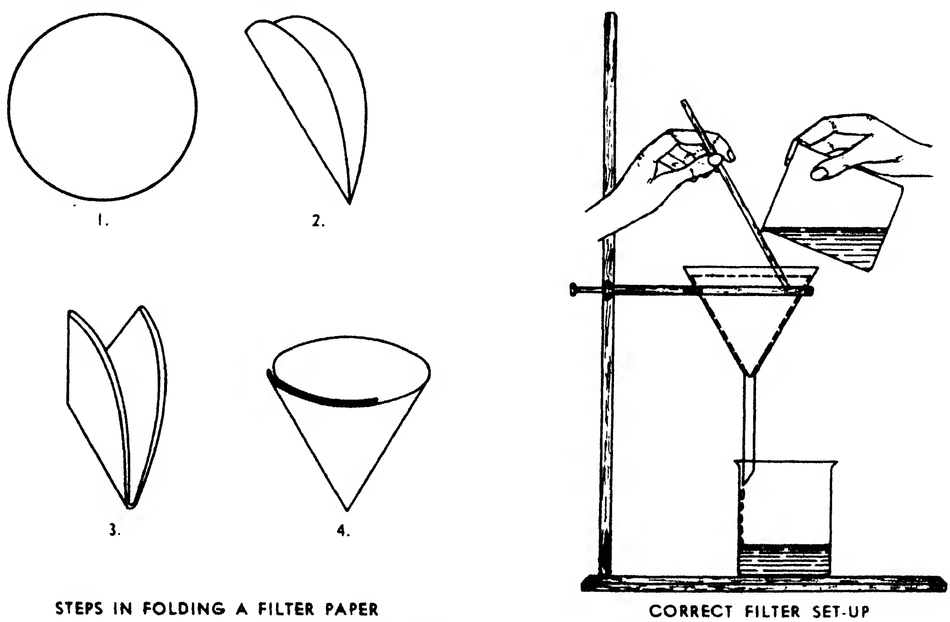

FIG. 180. PROCESS OF FILTRATION

Do colloidal particles settle out? ....

Can they be filtered out? ....

f) Emulsions

Place 3 ml. of oil in a test tube with 10 ml. of water. Shake vigorously and then allow to stand motionless for a few minutes. The oil (dissolved, separated) .... (in, from) .... the water.

Now add 3 ml. of a soap solution and shake vigorously again. Allow to stand. The liquids (do, do not) .... separate and an .... has been formed.

Questions:

1. A solution is always (colorless, clear) .... but not necessarily ....
2. Upon standing, the particles in a (solution, suspension) .... settle out.
3. Solids are usually more soluble in .... water while gases dissolve better in .... water.
4. Liquids which will not dissolve in each other are said to be ....
5. A substance which causes oil to remain suspended in water is called a(n) .... agent.
6. 1.65 g. of lime will dissolve in one liter of water at room temperature. Such a solution is (concentrated, dilute) ....; also (saturated, unsaturated) ....
7. The two parts of a solution are known as the .... and the ....

ANTIFREEZE

As the name implies an antifreeze is a solute added to a solvent to lower its freezing point. Such a solution is used in automobile radiators. Some type of alcohol is usually used for this purpose such as methanol (formerly called wood alcohol), denatured ethyl alcohol (grain alcohol) with some substance added to make it unfit for drinking, glycerine and ethylene glycol (sold as Prestone, Zerex, etc.). Glycerine and ethylene glycol have a high boiling point, hence do not boil away easily, making them good antifreeze solutes. Substances containing calcium chloride should not be used as an antifreeze because they are injurious to the metals in the cooling system.

Since the addition of an antifreeze to water increases or decreases the

specific gravity of the solution as it lowers the freezing point it is possible to determine the freezing point of an antifreeze mixture by determining its specific gravity. Table XLVI shows the specific gravity* and freezing points of various antifreeze solutions.

* Specific gravity is an abstract number which expresses how many times heavier a substance is than an equal volume of water.

SPECIFIC GRAVITY AND FREEZING POINT OF ANTIFREEZE SOLUTIONS

	Freezing point	
Ethyl Alcohol		
Sp. Gr. (20°C - 68°F)	*C*	*F*
.980	–5.0	23.0
.970	–9.4	15.1
.959	–16.0	3.2
.954	–18.9	–2.0
.947	–23.6	–10.5
.937	–28.7	–18.7
.921	–33.9	–29.0
.900	–41.0	–41.8
Glycerine		
1.049	–4.8	23.4
1.075	–9.5	14.9
1.101	–15.4	4.3
1.128	–23.0	–9.4
1.156	–34.7	–30.5
1.184	–38.9	–38.0
Ethylene Glycol (Prestone)		
Sp. Gr. (15.6°C - 60°F)	*C*	*F*
1.019	–3.9	25.0
1.026	–6.7	20.0
1.038	–12.2	10.0
1.048	–17.8	0.0
1.056	–23.3	–10.0
1.063	–28.9	–20.0
1.069	–34.4	–30.0
1.073	–40.0	–40.0

TABLE XLVI

MEASURING THE SPECIFIC GRAVITY OF LIQUIDS

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 100-103
Dull: *Modern Physics*, pages 42-46.
Fletcher: *Unified Physics*, pages 48-50.
Holley and Lohr: *Mastery Units in Physic* , pages 89-96.
Millikan: *New Elementary Physics*, pages 40-42.

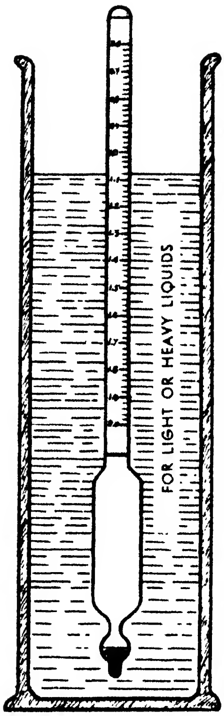

FIG. 181. HYDROMETER

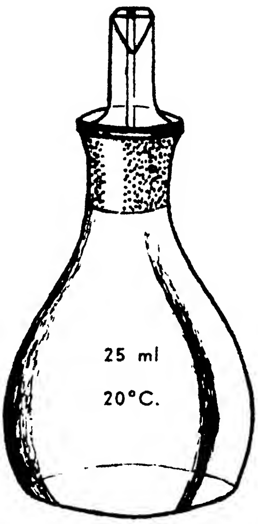

FIG. 182. SPECIFIC GRAVITY BOTTLE.

HYDROMETERS

The direct reading hydrometer, Fig. 181, is the type commonly used to test the specific gravity of liquids such as battery acid and antifreeze solutions. The scale of a direct reading hydrometer begins at 1.000 for liquids both lighter and heavier than water. Since liquids expand when heated and contract when cooled, the hydrometer scale is usually calibrated at 60°F (15.5°C). For accuracy, readings must be corrected for higher or lower temperatures. For heavy liquids the scale reads one plus a decimal (as 1.850); for liquid lighter than water the scale reads as a decimal only (as 0.966). Special hydrometers, such as those used to test antifreeze solutions, are marked to read directly in "freezing points.'

Demonstration:

Fill a tall cylinder with an alcohol-water mixture. Float a hydrometer in the liquid and read the position of the liquid on the scale. Using Table XLVI, determine the freezing point of this mixture.

Specific Gravity .... Freezing point....................

WEIGHING METHOD

A more exact method for determining the specific gravity of a liquid is by the use of the specific gravity bottle or pycnometer, Fig. 182. The pycnometer is made to hold a definite quantity of liquid (25 cc. or 50 cc.) at a definite temperature. To use, the pycnometer is weighed empty, then filled with pure water and carefully re-weighed. It is then emptied, carefully rinsed and filled with the liquid of unknown specific gravity to be tested. After being re-weighed, the specific gravity of the liquid is determined by the formula:

$$\text{Sp. Gr.} = \frac{\text{Weight of liquid}}{\text{Weight of water}}$$

If a pycnometer is available, the specific gravity of one or more liquids should be measured by this method.

OIL MIXTURES AND SLUDGE

REFERENCES

Sun Oil Company: *Lubrication of Industrial Machinery*
War Department —
TM-10-540 *Automotive Lubrication,* pages 10-45.

For lubricating the moving parts of machinery which are subjected to varying operating conditions, special oil mixtures, gear lubricants and greases have been developed.

OILS

The properties and types of motor oil have been discussed previously in connection with lubrication and the SAE numbering system.

Light machine oil (or SAE 10; Navy symbol 2110) processed to eliminate gumming, is used for small high speed bearing surfaces where shocks are mild and pressures even. It is applied through special oil cups in such parts as generators, starters and distributors.

Other special oils are penetrating oil, kerosene oil, flushing oil, valve and top cylinder oils. Each of these oils is prepared to provide lubrication where special conditions warrant.

GEAR LUBRICANTS

Gear lubricant is a heavy bodied oil, usually dark in color. It must have sufficient body to cushion and sustain the sudden, high pressure loads transmitted to the gear teeth surfaces and must cling to the teeth to protect them against metal-to-metal contact. It must be sufficiently fluid not to channel (gear teeth cutting a groove through the lubricant) nor impose undue drag on the motion of the parts, and must flow in ample supply to the bearings which support the gear shafts. Gear lubricants are used in transmissions, driving axle housings, steering gears, winch and hoist drive mechanism housings and similar units.

Some gears, such as hypoid rear axle gears, because of the extreme pressure and amount of friction between them, require a specially compounded lubricant. These are made by adding chlorine compounds, sulfur compounds and lead soaps to mineral oil. They are indicated by the letters (E.P.) indicating "extreme pressure."

GREASES

Greases are semifluid or semisolid lubricants, made by blending mineral oils and a metallic soap. Metallic, or grease soaps, are chemical compounds produced from soda, lime, aluminum, calcium, potassium, antimony and barium.

Lime or calcium soap greases are less affected by water than are other greases. Cup greases belong to this type and have a tendency, at temperatures above 175°F, to separate into oil and metallic soap.

Sodium soap greases are fibrous and stringy in appearance. They are not as resistant to water as calcium soaps but resist centrifugal "throw off" because of their greater adhesive property. They are used in high speed rotating units such as wheel bearings and universal joints.

Greases are used primarily on slow moving parts.

SLUDGE

The oil in the crankcase of all internal combustion engines is subject to contamination from both outside and inside sources. The product of this contamination is commonly known by the name "sludge."

Outside contamination is due to dust and dirt present in the air. Under certain conditions these impurities may be present in such quantities as to completely wreck an engine. This hazard is greatly reduced by the proper use of air cleaners (Fig. 155) and oil filters (Fig. 183 A and B).

Five sources of inside contamination are 1) carbon, 2) water, 3) dilution of the oil with gasoline, 4) acids, and 5) metal particles. Carbon and unburned fuel dilution are products of "incomplete combustion," while water, acid and metallic contaminants are "by-products" of combustion. Carbon, formed by incomplete combustion, may deposit behind piston rings and work its way into the lubricating oil. Water, produced by the condensation of combustion gases, finds its way into the lubricating oil where it combines with other contaminants to form emulsions or "sludge."

Sludge is the engine's most dangerous enemy. It will foul piston rings, clog injectors, accelerate carbon formation, restrict or even close oil lines, leading ultimately to lubricating system failure. As previously stated sludge is brought about by the presence of water, fuel dilution, acid formation, carbon and other solids, churned together by the revolutions of the engine into an "emulsion." Once started, the growth of sludge continues rapidly.

Metallic particles act as abrasives and rapidly increase in quantity as the rate of engine wear increases. These abrasives are not only damaging to the working parts of the engine but form excellent "binders." Metallic contaminants may also react with the products of oxidation and form corrosive acids. Using these binders as a nucleus, carbon and sludge form first, "gummy," then later, hard, tenacious deposits which cause rings to stick and ultimately lead to mechanical failure.

Sludge also forms in the cooling system of a motor, due to the action of water and antifreeze solutions on the metal and rubber parts of the motor and radiator. This sludge will eventually clog the radiator unless the cooling system is periodically flushed out and clean water added.

OIL FILTERS

A "by-pass" type oil filter is shown in Fig. 183A. Dirty oil from the crankcase enters the filter under pressure through the inlet and restriction (1), passes through the molded filtering element (3), through special filter cloth winding (4), through perforated metal screen and into collector tube (5), and back to the engine through outlet (6). Only a small percentage of the oil is by-passed to the filter at any one time, but over a period of time all the oil is cleaned. Should the filter become clogged the oil will continue to be circulated through the engine but will no longer be cleaned. The filtering element should be changed before clogging occurs.

Fig. 183B shows the parts of an oil cleaner dis-assembled. The parts are: 1) cover nut, 2) cover nut gasket, 3) top cover, 4) top cover gasket, 5) top cover spring, 6) filtering element, 7) case assembly, 8) drain plug, 9) bracket, 10) bracket bolt, 11) bracket lock washer, and 12) bracket nut.

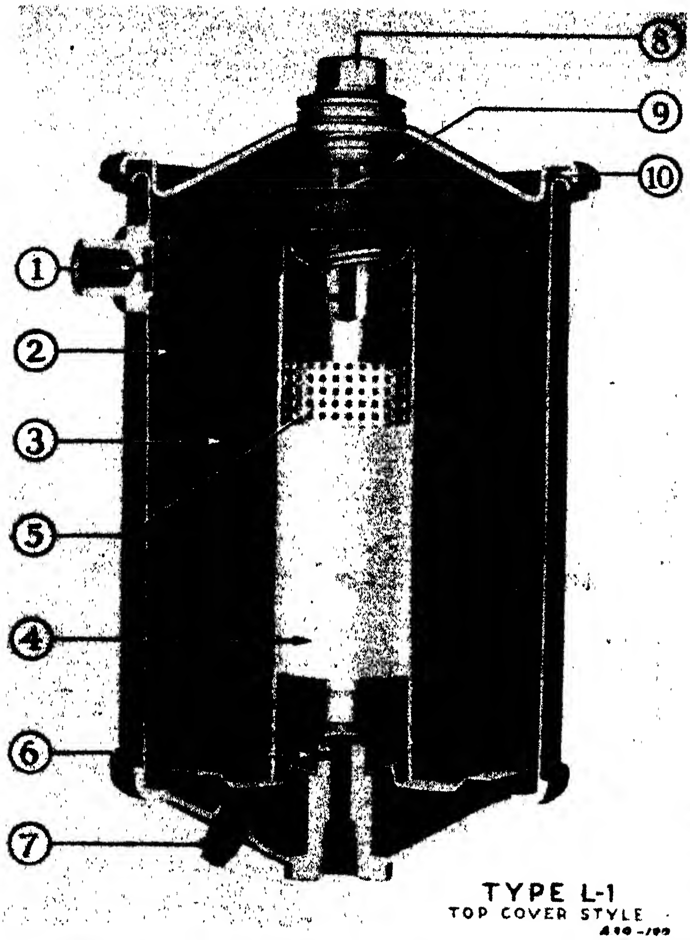

FIG. 183A. "OUTSIDE-IN" BY PASS OIL FILTER. (Courtesy, A. C. Spark Plug Division, General Motors Corporation.)

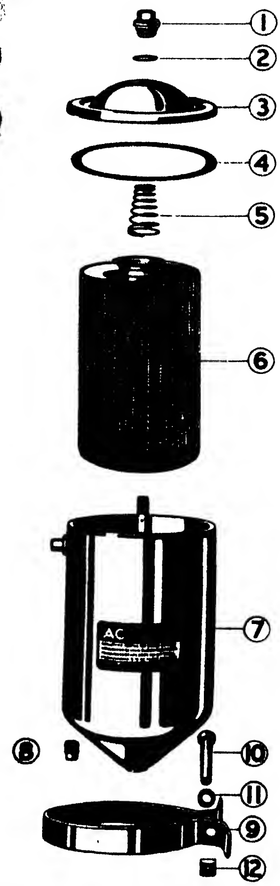

FIG. 183B. PARTS OF AN OIL FILTER. (Courtesy, A. C. Spark Plug Division, General

Demonstration:

Secure some used crankcase oil from an automobile. Allow it to stand for some time, then examine it for any suspended material that may have settled out. Rub a little of the oil between the fingers to determine whether it contains any gritty, metallic particles.

Questions:

1. How do gear lubricants and grease differ? ....

....

2. What is meant when a lubricant is said to "channel"? ....

....

3. Why do hypoid gears need a special type of lubricant? ....

....

4. What type of grease must be used for a water pump? ....

....

5. Name several causes of "sludge" forming in motor oil? ....

....

6. Name several ways in which sludge is harmful to a motor ....

....

7. How can the formation of sludge be retarded? ....

....

GAS LAWS

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 136-141; 243-246; 313-322.
Dull: *Modern Physics*, pages 63-72; 223-226; 278-282.
Fletcher: *Unified Physics*, pages 65-67; 208-210; 271-275.
Holley & Lohr: *Mastery Units in Physics*, pages 46-57; 275-282; 347-354.
Millikan: *New Elementary Physics*, pages 54-60; 188-198; 268-277.
War Department —
TM 10-565 *Automotive Brakes*, pages 29-41.
TM 1-405 *Aircraft Engines*, pages 8-10.
TM 570 *Internal Combustion Engines*, pages 12-74; 64-65.

BOYLE'S LAW

The behavior of gases, under varing temperatures and pressures, is found to follow definite physical laws. After much investigation, Robert Boyle established that the change in the volume of a gas is inversely proportional to the pressure, temperature being constant.. This fact, now known as "Boyle's Law" is illustrated in Fig. 184. When the pressure is

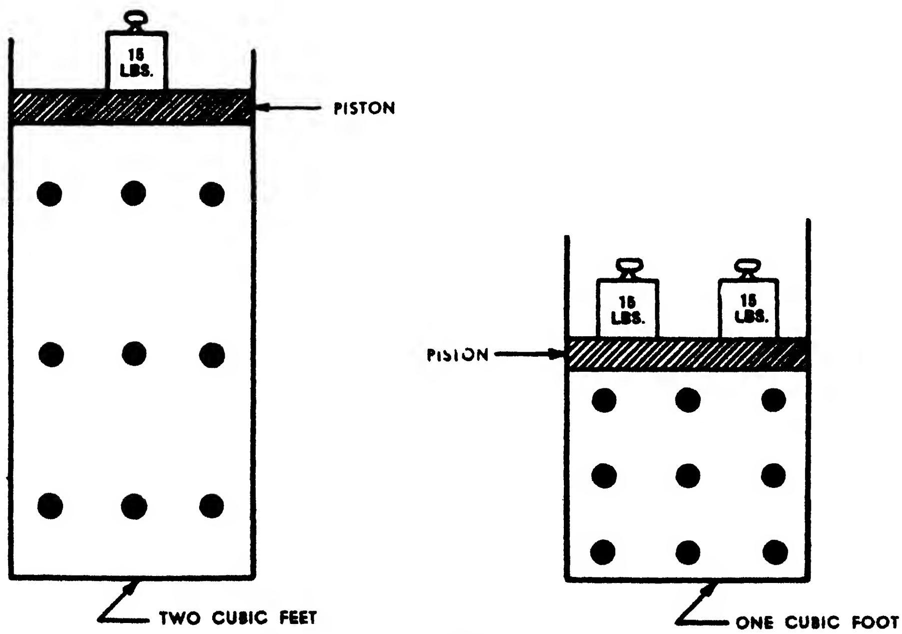

FIG. 184. BOYLE'S LAW.

doubled, the volume is just one half as much, the molecules having been crowded more closely together. (Note that the number or size of the molecules has not changed.) This law is easily demonstrated with a tire pump by holding the air hose closed with the thumb and pushing down on the pump handle with the other hand. The law is applied on every compression stroke of a gasoline or diesel engine. Other applications are found in door closing checks, recoil mechanisms, pneumatic tires, air hammers, air brakes, etc.

CHARLES' LAW

There are also many common examples to show the effect of changing

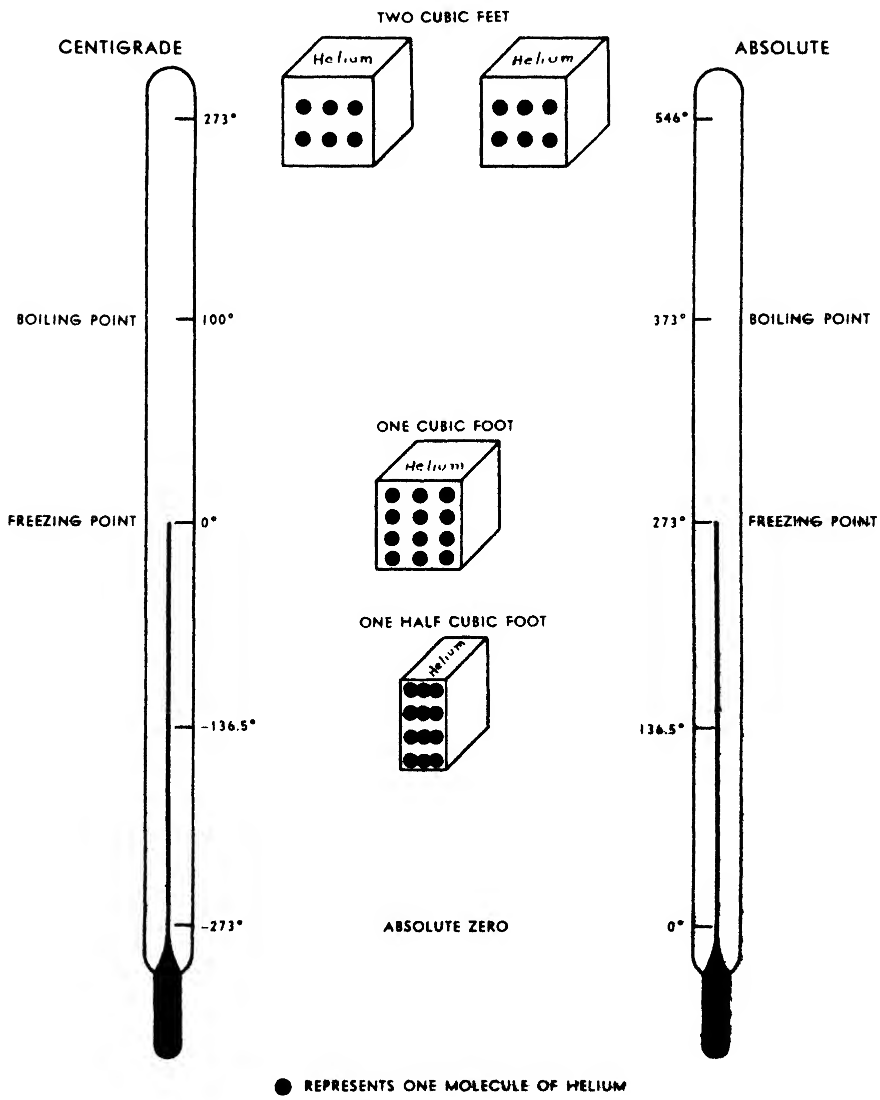

FIG. 185. CHARLES' LAW

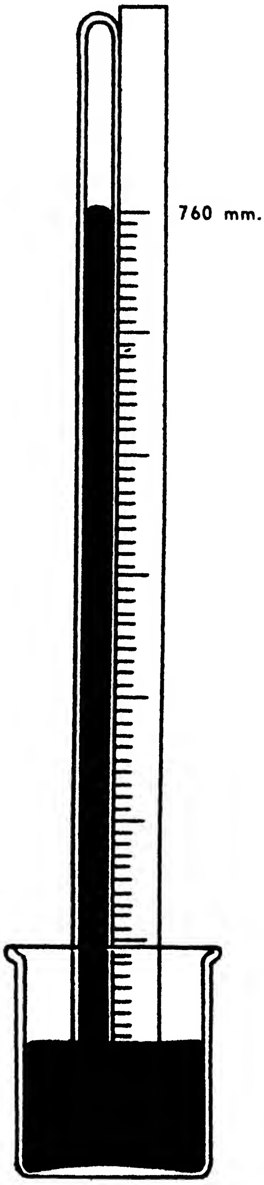

FIG. 186.
SIMPLE BAROMETER.

the temperature on the volume occupied by a gas. An automobile tire may seem underinflated in the cool of early morning, yet due to the heat of the road and travel, may expand until a "blow out" occurs. It is the expansion of gas, caused by the heat of burning gasoline or fuel oil, that produces the pressure on the power stroke of a gasoline or diesel engine.

The expansion of gas due to heat follows a definite law, also. This law, known as Charles' Law, states that the volume of a gas is directly proportional to the Absolute temperature, the pressure remaining constant. (See Fig. 185.)

MEASUREMENT OF PRESSURE

The standard selected for atmospheric pressure is 760 mm. of mercury. This means that the pressure exerted by the weight of the air is sufficient to support a column of mercury 760 mm. (30 inches) high. This is equivalent to 14.7 lbs. per square inch. The barometer, Fig. 186, is an instrument used to measure air pressure.

Gas pressure is also measured by other types of gages. The Bourdon gage, Fig. 187A, is a type often used. When gas, under pressure, enters the Bourdon tube, the tube tends to straighten out. This tube is connected to a rotating pointer, by means of a gear wheel, which indicates the pressure being exerted.

A much used pressure gage is a tire gage, Fig. 187B. When the gage is properly seated on the valve mouth, the deflator in the gage depresses the valve core pin and air from the tire passes through "Filter Washer," concentrating pressure on the leather plunger cup inside the barrel. The plunger "Cup Assembly" actuates the indicating bar. The spring governs the exact distance the indicating bar moves (an application of Hooke's Law). Gages are carefully calibrated to constantly give accurate readings.

The construction of a tire valve, used to hold air in a tire under pressure, is shown in the open (Fig. 187C) and closed (Fig. 187D) positions.

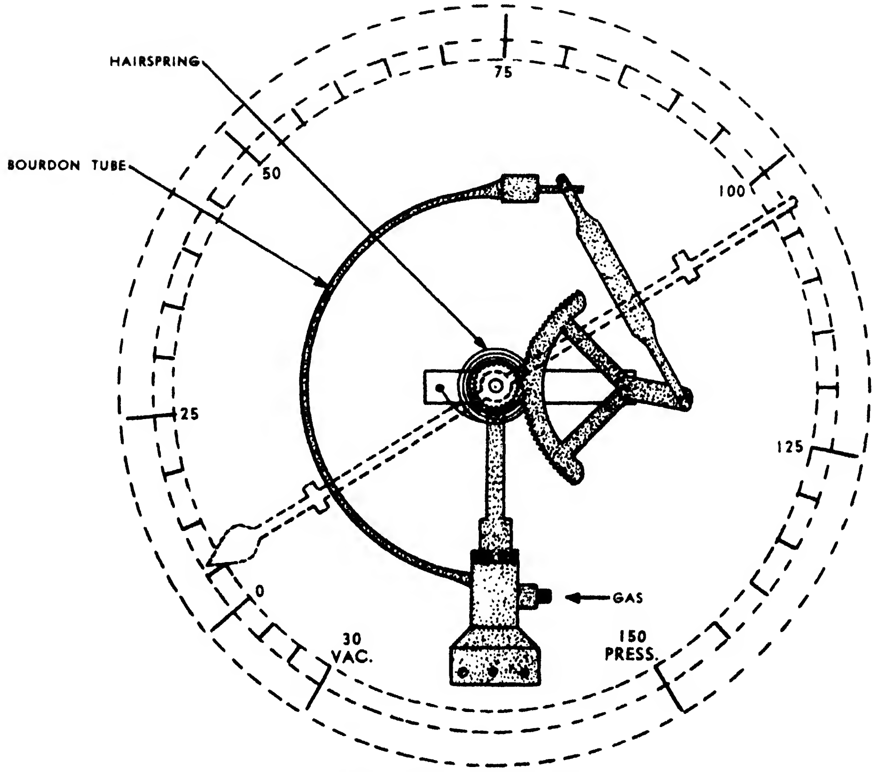

FIG. 187A. BOURDON GAGE.

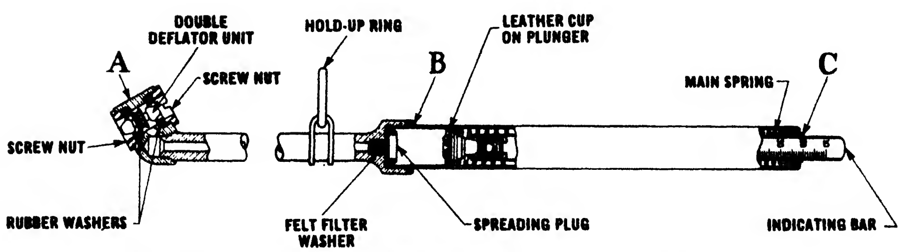

FIG. 187B. TIRE PRESSURE GAGE. (Courtesy, A. Schrader's Son.)

These valves serve under all kinds of severe conditions on civilian and military equipment with great dependability.

MEASUREMENT OF TEMPERATURE

In stating Charles' Law, mention was made of "Absolute Temperature." Fig. 188 shows the three commonly used temperature scales, namely Fahrenheit, Centigrade and Absolute. Zero on the Fahrenheit scale is the lowest temperature obtainable with a mixture of salt and ice; zero on the Centigrade scale is the freezing point of pure water; zero on the Absolute scale is supposed to represent the absence of all heat. It will be noted that 0°A is –273°C. While this temperature has never been

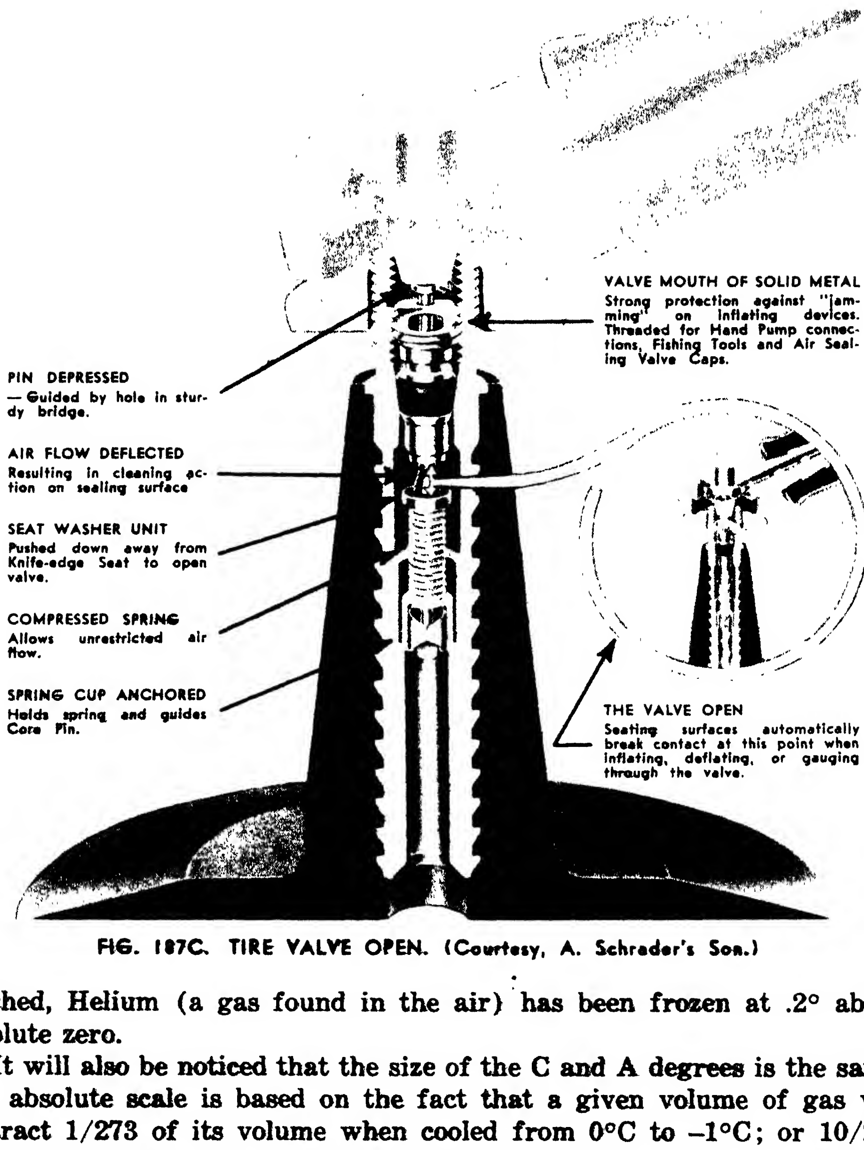

FIG. 187C. TIRE VALVE OPEN. (Courtesy, A. Schrader's Son.)

reached, Helium (a gas found in the air) has been frozen at .2° above absolute zero.

It will also be noticed that the size of the C and A degrees is the same. The absolute scale is based on the fact that a given volume of gas will contract 1/273 of its volume when cooled from 0°C to –1°C; or 10/273 when cooled from 0°C to –10°C. From this it would seem that if a gas were cooled 273° its volume would become nothing, and matter would thus be destroyed. This does not happen, however, because all gases change to a liquid or solid long before this degree of cooling is attained. For a more complete discussion of Boyle's and Charles' Laws, the student should refer to more advanced books on the subject. From a practical view point, these laws are applied in the operation of internal combustion engines. A discussion of the essential parts and the operating principles of the gasoline and diesel engines follows.

INTERNAL COMBUSTION ENGINES

An internal combustion engine mixes air with fuel, ignites the mix-

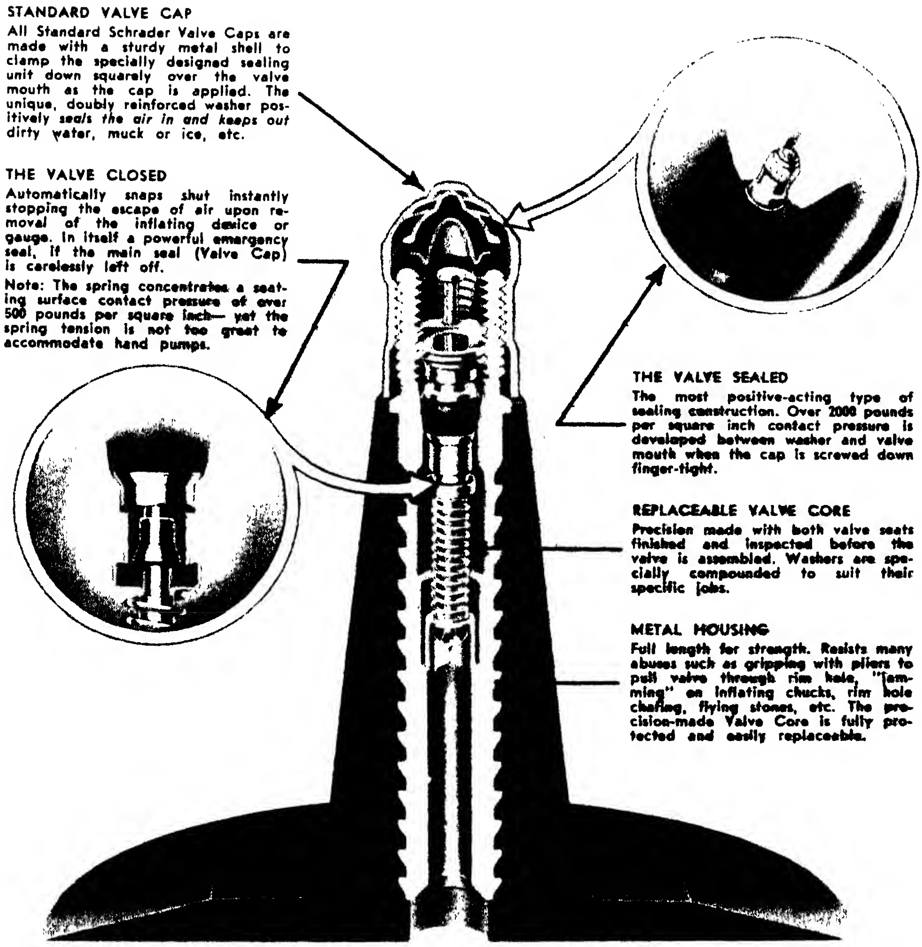

FIG. 187D. TIRE VALVE CLOSED. (Courtesy, A. Schrader's Son.)

ture and converts the energy thus released into mechanical motion. It is said that the modern engine had its beginning with the "gunpowder engine" made by Christian Huyghens in 1680. In this engine, a charge of gunpowder was exploded in the cylinder to move the piston. While this principle was impractical, it opened the field for scientific investigations which led to the present day engines. Many other investigators added their bit to the development of a practical engine, but Dr. N. A. Otto of Germany is credited with making practical the 4-stroke cycle now universally used and known as the "Otto cycle."

ESSENTIAL PARTS

The essential parts of an internal combustion engine are shown in Fig. 189. These consist of a perfectly round cylinder fitted with a movable piston on which several piston rings are used to insure a gas-tight fit between the piston and the cylinder wall. This piston is connected to the crankshaft by means of a connecting rod. In the upper part of the cylin-

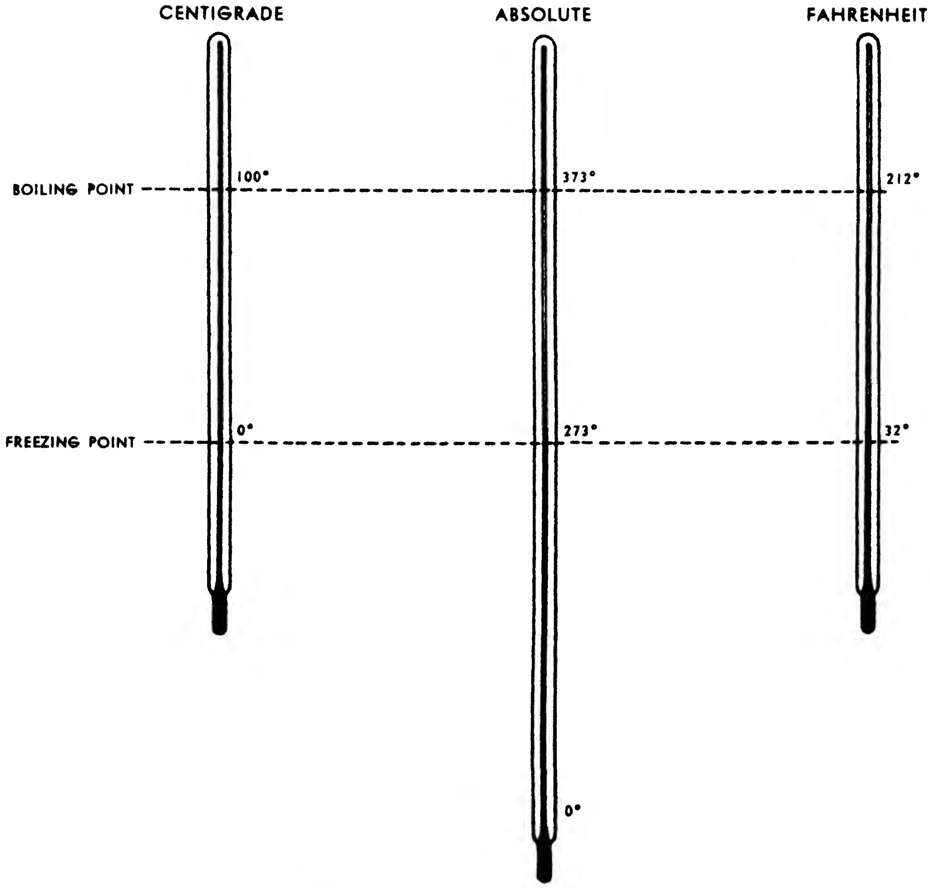

FIG. 188. TEMPERATURE SCALES COMPARED.

der are the intake and exhaust valves and a spark plug (in a diesel engine, the spark plug is replaced with a fuel injector) Fig. 190A.

DIESEL FUEL INJECTION SYSTEMS

The heart of the diesel engine is the fuel injection system which must, under high pressure, measure and force the exact amount of fuel to each cylinder at exactly the proper time in every cycle of each piston. A four cylinder, four cycle diesel engine, running 1500 r.p.m. requires 3000 fuel injections per minute — 180,000 injections per hour. If this engine uses two gallons of fuel an hour, the fuel must be divided into 180,000 parts and forced into the cylinder against the compression pressure of 500 or 600 pounds per square inch. Modern engines use the solid injection system. This consists of a small pump and nozzle for each cylinder, shown in Fig. 190B. The pump is so accurately made that it can produce pressures up to 20,000 pounds per square inch to force oil through the small openings in the nozzle at 780 miles per hour. Referring to Fig. 190A the fuel is forced through the valve (1) into the pre-combustion chamber (2) where it is partially burned. It is then blown through the large opening (3) into the main combustion space for complete combustion. The nozzle and

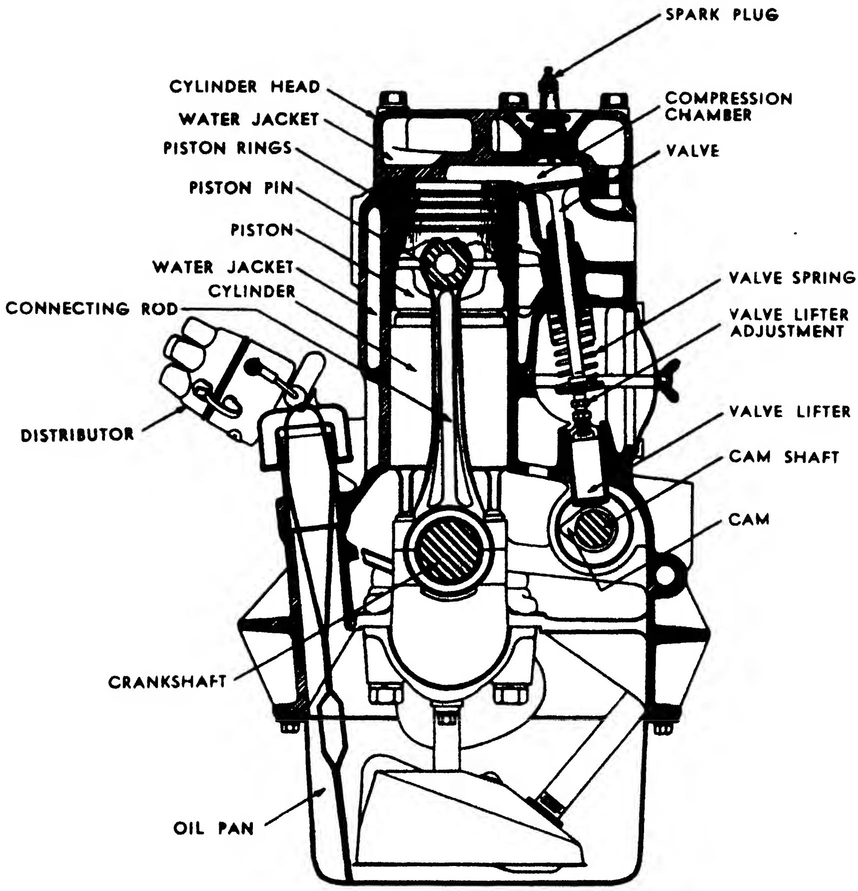

FIG. 189. PARTS OF AN ENGINE.

pre-combustion chamber are placed at an angle in order to distribute the heat uniformly over the upper surface of the piston. The water jacket (4) and heat insulator (5) help maintain the correct temperatures for smooth, efficient operation.

Fig. 190B illustrates the action of the fuel pump and injector. Oil enters the fuel inlet, filling the injector. As the plunger moves down, the fuel inlet opening is covered.

This stops the flow of oil from the fuel tank and allows the plunger to start forcing the oil downward, building up a tremendous pressure. This pressure, acting on the lower end of the needle valve plunger, lifts the needle valve off its seat. A free passage is thus opened, so the oil can be forced out of the fine holes in the spray tip. Injection is timed to occur just before the piston of the engine reaches the top of its stroke.

TYPES OF ENGINES

As has been mentioned, the two most familiar types of internal combustion engines are the gasoline and diesel. In general appearance they look almost alike, have many similar parts and both burn a liquid fuel within the cylinder. There is one fundamental difference. In the gasoline

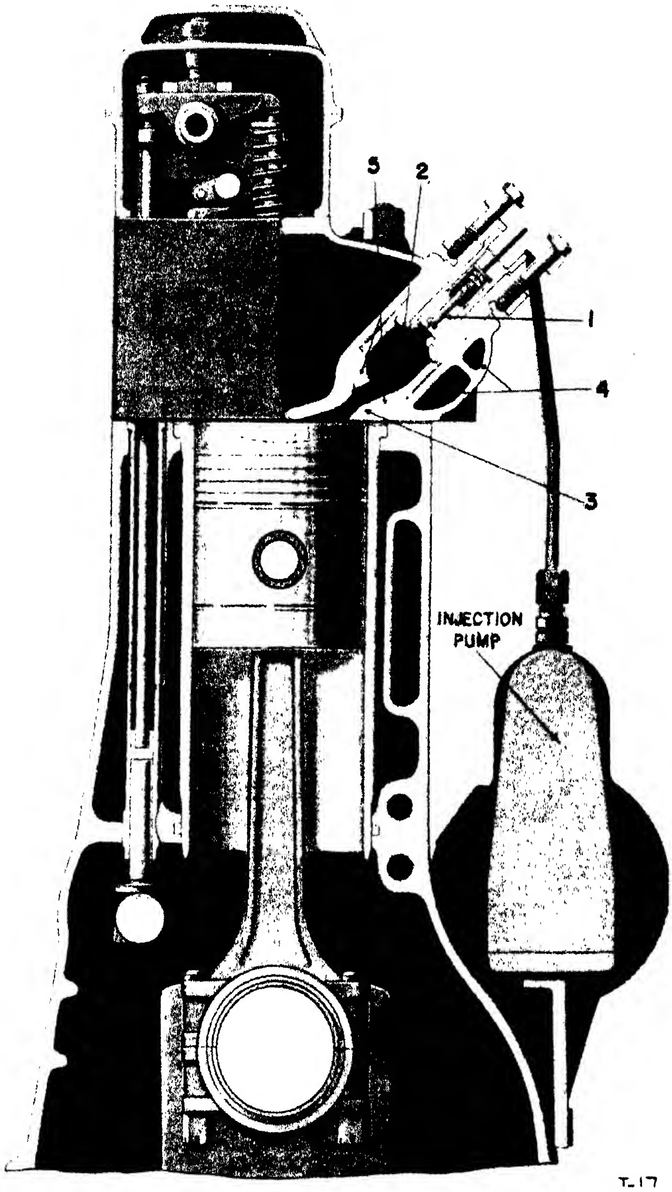

FIG. 190A. FUEL INJECTOR FOR DIESEL ENGINE. (Courtesy, International Harvester Company.)

engine the fuel and air are mixed before they enter the cylinder (by the carburetor): in the diesel engine the fuel and air are mixed within the cylinder. The gasoline engine compresses the mixture of gasoline and air which is ignited by an electric spark. The diesel engine compresses only a charge of air (the heat caused by this compression raises the temperature of the compressed air to about 1000°F), and the fuel, then forced into the cylinder by an injector (Fig. 190B) is ignited by the heat of compression.

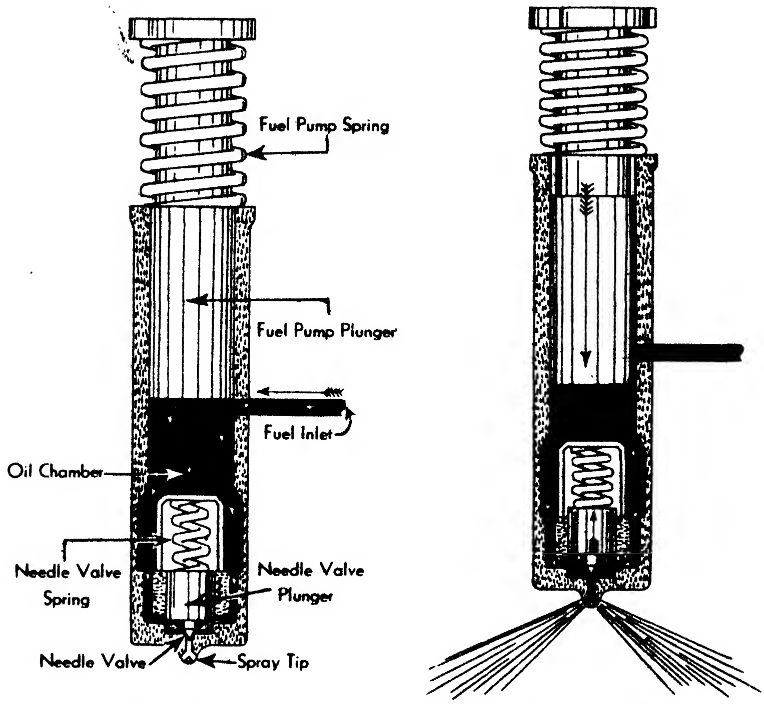

FIG. 190B. FUEL INJECTOR FOR DIESEL ENGINE.
(Courtesy, General Motors Corporation.)

COMPARISON OF GASOLINE AND DIESEL ENGINE CYCLES

INTAKE STROKE

Gasoline

On the downward stroke of piston, intake valve opens and atmospheric pressure forces air through the carburetor where it picks up a metered charge of fuel, then the mixture goes past the valve into the cylinder space vacated by the piston.

Diesel

On the downward stroke of piston, intake valve opens and atmospheric pressure forces air into the cylinder space vacated by the piston. Cylinder fills with the same quantity of air regardless of load on the engine.

COMPRESSION STROKE

On the upstroke of piston, valves are closed, and the mixture is compressed, usually to from 70 to 125 lbs. per sq. in., depending on the antiknock characteristics of the fuel. (Application of Boyle's Law.)

On upstroke of piston, valves are closed, and air is compressed to approximately 625 lbs. sq. in. (Application of Boyle's Law.)

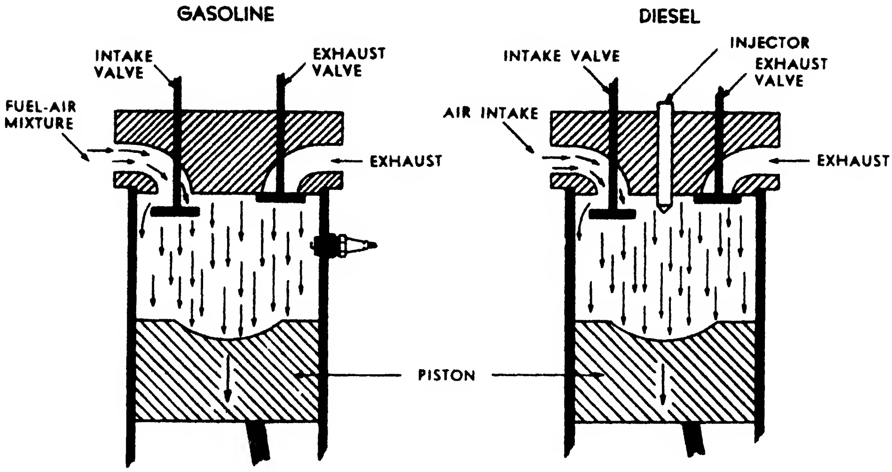

FIG. 191. INTAKE STROKE.

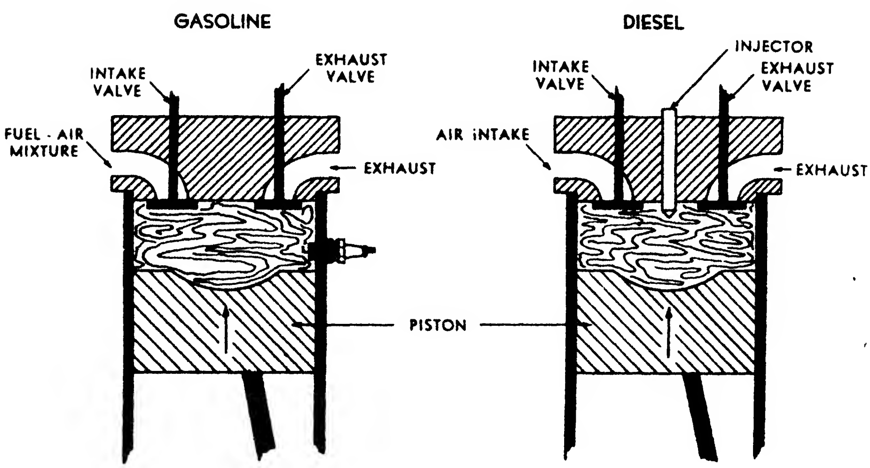

FIG. 192. COMPRESSION STROKE.

POWER STROKE

Compressed fuel-air mixture is ignited by electric spark. Heat of combustion causes forceful expansion of cylinder gases against piston, resulting in power stroke. (Application of Charles' Law.)

High compression produces sufficienty high temperature for spontaneous ignition of the fuel which is injected near the end of the compression stroke. Heat of combustion causes forceful expansion of cylinder gases against piston, result of power stroke. (Application of Charles' Law.)

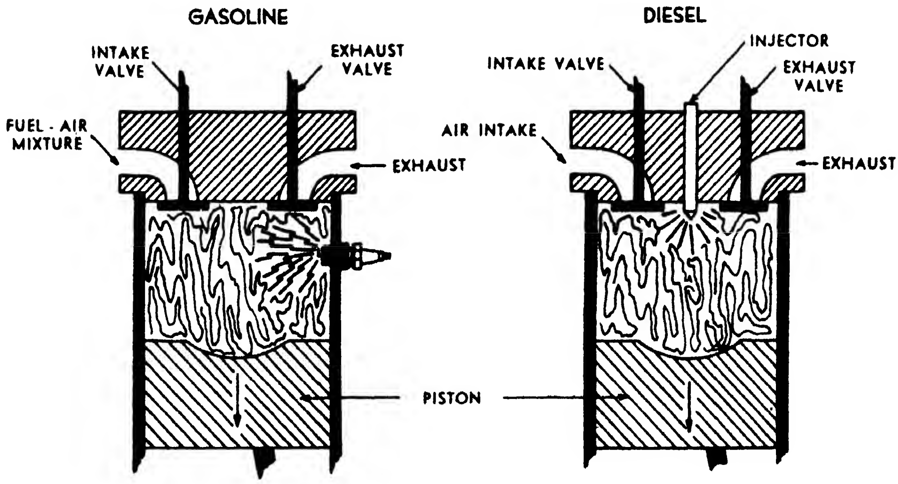

FIG. 193. POWER STROKE.

EXHAUST STROKE

Upstroke of piston, with exhaust valve open forces cylinder gases out, making ready for another intake stroke.

Upstroke of piston, with exhaust valve open, forces cylinder gases out, making ready for another intake stroke.

COMPRESSION RATIOS

In the foregoing comparison of gasoine and diesel engines it is shown that the compression is much higher in the cylinder of a diesel engine than in a gasoline engine. Since the higher the compression ratio the greater the efficiency of the engine, *WHY* do the two engines have different compression ratios? Fig. 195 shows the compression ratios of gas-

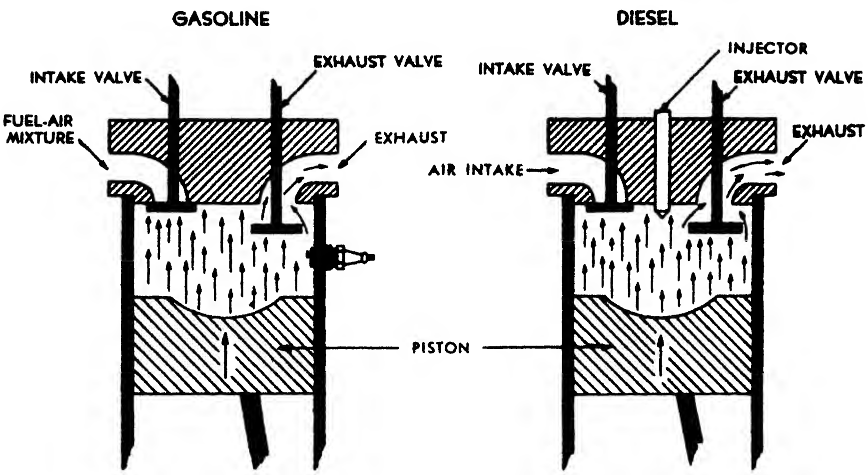

FIG. 194. EXHAUST STROKE.

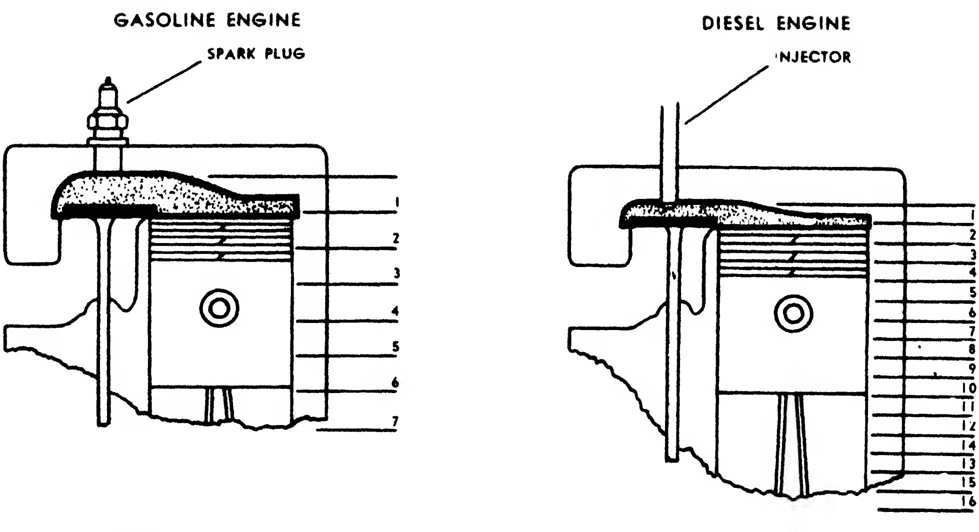

FIG. 195. COMPRESSION RATIOS.

oline and diesel engines. The compression ratio of an engine is found by the formula

$$\text{Compression ratio} = \frac{\text{Displacement Volume} + \text{Clearance Volume}}{\text{Clearance Volume}}$$

If the compression ratio is 6:1 it means that when the cylinder is full of

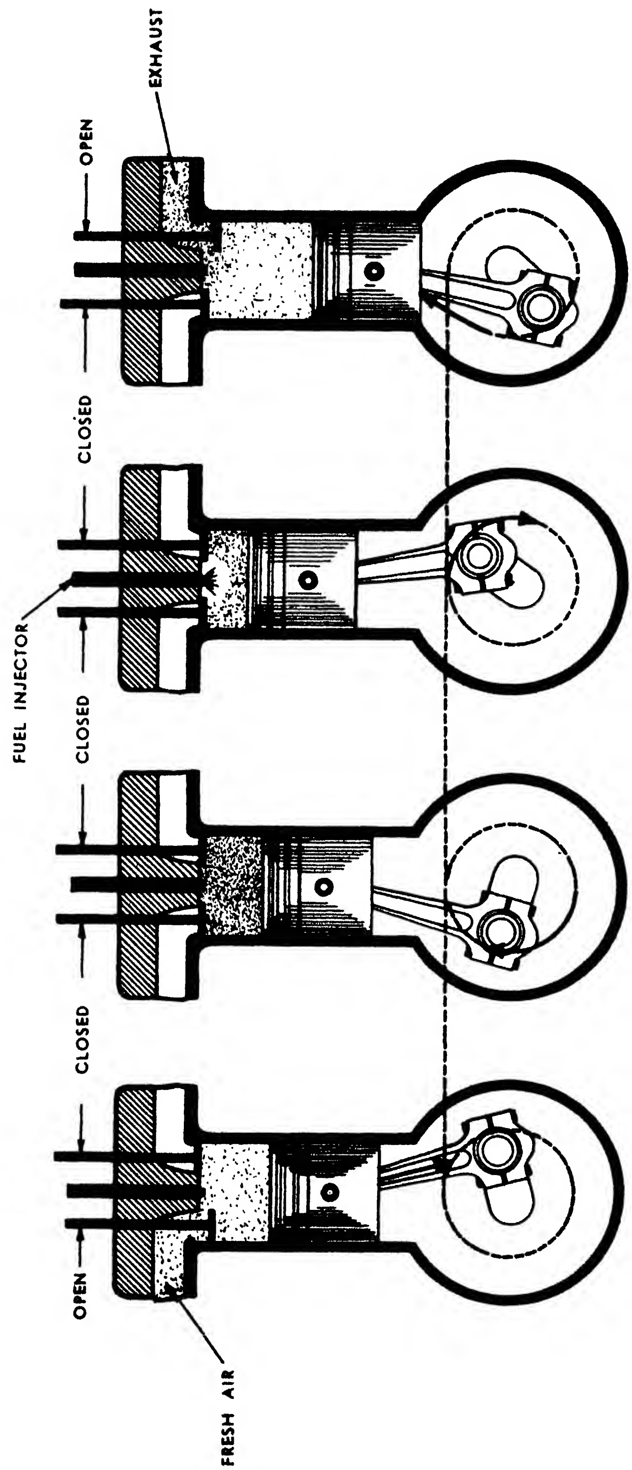

FIG. 196. FOUR STROKE CYCLE.

air or a mixture of gasoline and air with the piston at the bottom of the stroke, it is squeezed to one-sixth of its volume when the piston reaches the top of the stroke.

When an air or gas-air mixture is compressed 16 times it is heated to about 1000°F. If a compression ratio this high were used in a gasoline engine, this high temperature would start the mixture of air and gasoline burning in the cylinder long before it should. The mixture would start burning while the piston was on its up-stroke and cause a violent "knock," or even force the piston back down the cylinder and cause the engine to start running backwards. This is prevented in the diesel engine because the fuel is injected into the compressed air at the correct time for the power stroke.

FOUR STROKE CYCLE

In this engine, four strokes of the piston are required to complete one power producing cycle. A stroke is the total movement of the piston from top dead center (T.D.C.) to bottom dead center (B.D.C.) of the crankshaft, or vice versa, this being equal to 180° of crankshaft or flywheel movement. A cycle consists of four movements (strokes) of the piston.

Fig. 196 illustrates the four stroke cycle.

Stroke 1. Admission or intake stroke

With the piston starting at T. D. C., exhaust valve closed, intake valve open, the piston moves downward creating a partial vacuum in the cylinder drawing air (into the diesel engine) or a mixture of air and fuel (gasoline engine) through the intake valve, completely filling the cylinder.

Stroke 2. Compression Stroke

The piston travels from B.D.C. to T.D.C., compressing the air or air-fuel mixture drawn in during the intake stroke, both the exhaust and intake valves remaining closed.

Stroke 3. Power stroke

The highly compressed fuel charge is ignited by a spark at the spark plug (gasoline engine) or fuel is injected into the highly compressed hot air and ignited (diesel engine). The heat of combustion expands the gases in the cylinder, building a combustion pressure four times as great as the compression pressure (Charles' Law) and forces the piston downward to B.D.C.

Stroke 4. Exhaust Stroke

When the piston reaches B.D.C., the exhaust valve opens and remains open while the piston again moves upward to T.D.C. position, forcing the burned gases out of the cylinder through the exhaust valve port.

During the four strokes (one cycle) the crankshaft has made two complete revolutions (720°) while the camshaft has made only one revolution, opening and closing the exhaust valve only once. If the engine is a multi-cylinder one, this working cycle is merely repeated in proper sequence

by the other cylinders: if a single cylinder engine, the sequence is aided by the inertia of the flywheel. The movements of the piston in the cylinder are correctly "timed" with the valve mechanism, so that the valves open and close at exactly the correct intervals. In the discussion of the four stroke cycle the valves were assumed to open and close at T.D.C. or B.D.C., but actually the valves do not open or close at these points which results in an overlapping of the power strokes, see Fig. 197. This overlapping produces a smoother flow of power.

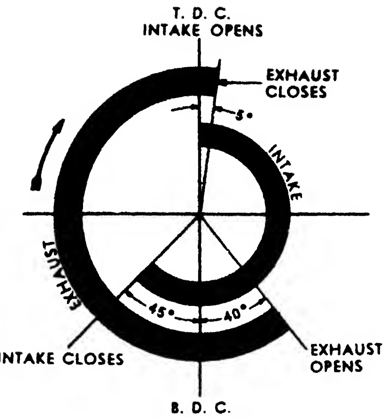

FIG. 197. VALVE OVERLAP.

TWO STROKE CYCLE

The two-stroke cycle is used in order to obtain a power stroke for each revolution of the crankshaft. (The four stroke cycle has only one power stroke during two revolutions of the crankshaft. See Fig. 196.)

For the same engine, the two-stroke cycle should give twice the power of the four-stroke cycle, but because of lower efficiency this is not altogether true. Fig. 198 illustrates the two-stroke cycle.

INTAKE AND COMPRESSION STROKE

On the upstroke of the piston, air (in a diesel engine) or fuel-air mixture (gasoline engine) is forced into the cylinder and compressed. At the top of the stroke the fuel is sprayed in the hot compressed air (diesel engine) and ignited, or the spark ignites the fuel-air mixture (gasoline engine), the heat expanding the gases and forcing the piston downward (the power stroke).

POWER AND EXHAUST STROKE

When the piston nears the bottom of the power stroke, the exhaust port or valve opens, allowing the hot, burned gases to leave the cylinder. As the piston moves further downward, the intake port in the cylinder wall near the lower end is uncovered. Intake and exhaust take place at the same time, and the cycle is ready to be repeated.

THE INTERNAL COMBUSTION ENGINE PUTS MOLECULES TO WORK

Gases, like other forms of matter, are made up of small particles called molecules. The molecules of a gas are in rapid motion like a swarm of angry bees. At room temperature and atmospheric pressure each molecule travels at the average speed of 1000 miles per hour. As they speed about, they bounce against each other and the sides of their container.

In an engine cylinder filled with air or a fuel-air mixture, the tiny molecules pound against the sides of the cylinder and the top of the piston. As the piston is moved upward the molecules are pushed closer together. (Boyle's Law). Because there is less space for them to move about in, they hit the walls and piston top more often. Their constant

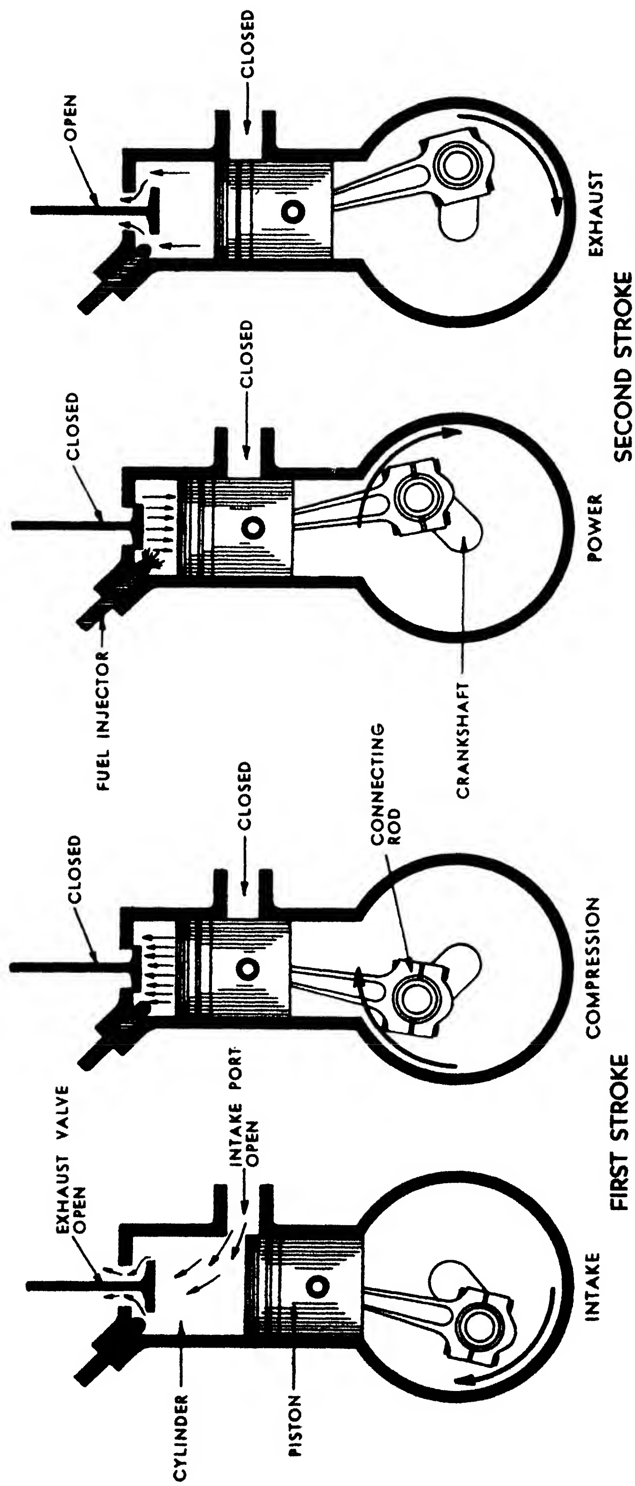

FIG. 198. TWO STROKE CYCLE.

pounding produces pressure and the more often they hit the higher the pressure goes.

To compress a gas requires work. This work shows up as heat in the compressed gas. In the diesel engine, the air is heated to the temperature of red hot iron by this pressure. When a gas gets hot, it means the molecules are moving faster. The faster they move, the more often they hit the walls of the cylinder and the greater is the pressure. The crowding of the molecules closer together and increasing their speed of motion (due to heat of compression) makes a great pressure in the cylinder because the molecules strike more often and with greater force. The molecules are in this condition at the end of the compression stroke. At this instant, more heat is produced by the combustion of the fuel sprayed into the hot compressed air (diesel engine) or by the ignition of the fuel-air mixture, a spark jumping the gap in the spark plug (gasoline engine). The heat, caused by the burning fuel, speeds up the motion of the molecules to a terrific velocity. They pound against the top of the piston like trillions of tiny pile drivers. They hit so fast and so often that the piston is pushed downward with a tremendous smooth force, turning the crankshaft and causing the engine to "run."

Questions:

1. The volume occupied by a given weight of gas varies with a change in .... and ....
2. Increased pressure on a gas (decreases, increases) .... its volume; increased temperature .... its volume.
3. The volume of a gas is (directly, inversely) .... proportional to the pressure, and .... proportional to the .... temperature. These facts are known as .... law and .... law respectively.
4. Temperatures are measured by three different systems, namely ...., ... and .... The size of the degrees in both the .... and .... is the same.
5. Air (or gas) pressure is measured in .... square inch or .... of mercury.
6. Two types of internal combustion engines are the .... and ....
7. The .... engine is the most efficient type because its compression ratio is (higher, lower) ....
8. The compression ratio of an internal combustion engine is calculated b the formula ....

9. The fuel of the gasoline engine is ignited by .... while that used in the diesel engine is ignited by ....
10. Fuel for a gasoline engine is measured by the ....; for the diesel engine by the ....
11. Gasoline engines cannot use as high a compression ratio as a diesel engine because ....
12. Internal combustion engines are made in .... and .... stroke cycles.
13. The letters T.D.C. and B.D.C. stand for .... and ....
14. In engine operation, a stroke is ....
15. The .... cycle engine delivers a power stroke during each revolution of the crankshaft; a .... cycle engine delivers a power stroke during two revolutions of the crankshaft.
16. The power in the cylinder of an internal combustion engine is caused by the rapid motion of .... The motion of these particles is increased by .... and pressure.

BERNOULLI'S PRINCIPLE

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 89-91.
Dull: *Modern Physics*, pages 122-123; 580-581.
Fletcher: *Unified Physics*, pages 185-191
Holley and Lohr: *Mastery Units in Physics*, page 55.
Millikan: *New Elementary Physics*, pages 116-118.
War Department —
TM-10-550 *Fuels and Carburetion*, pages 32-38.

Change in speed of flow affects the pressure which a fluid exerts. This fundamental principle, first explained by Daniel Bernoulli, states that when the speed of a fluid is great, the pressure is small; and when the speed is small the pressure is great. It will be seen by studying Fig. 199 that the same volume of liqud must pass the ponts A, B and C when flowing through a constricted tube. For this to happen the liquid must move

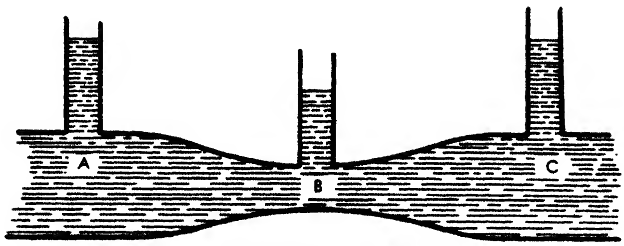

FIG. 199. BERNOULLI'S PRINCIPLE.

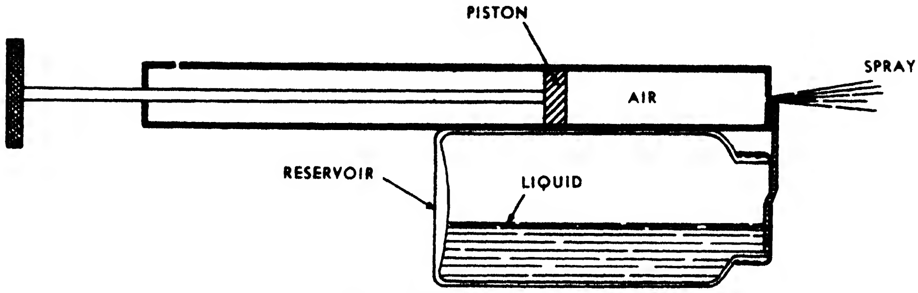

FIG. 200. INSECT SPRAY.

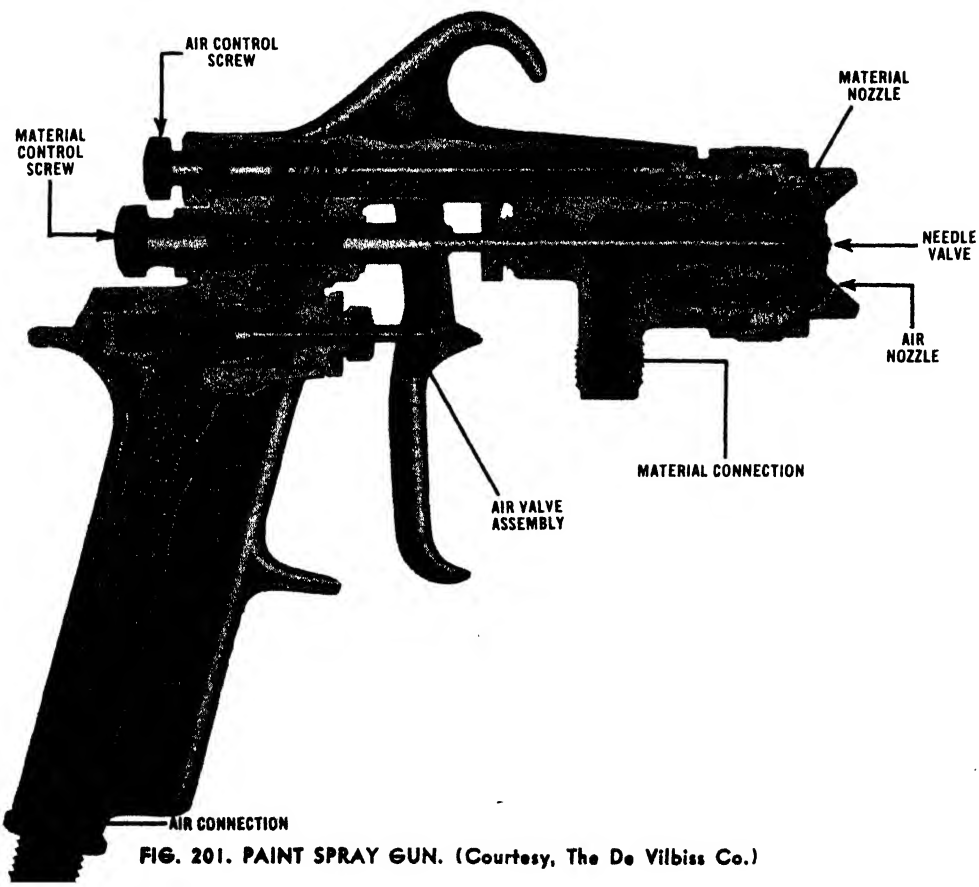

FIG. 201. PAINT SPRAY GUN. (Courtesy, The De Vilbiss Co.)

faster where the cross-sectional area of the tube is smallest. Some of the potential energy possessed by the liquid at A has been converted into kinetic energy at B. As the liquid passes on to point C, the speed decreases and the excess kinetic energy again changes to potential energy.

APPLICATIONS OF BERNOULLI'S PRINCIPLE

1. The atomizer or insect spray, Fig. 200, makes use of this principle. As the air rushes over the top of the vertical tube, the pressure in the tube is reduced and the higher air pressure in the tank forces the liquid up to the top of the tube where it is blown out in the form of a spray. This principle is also used in the spray gun for applying paint, illustrated in Fig. 201.

2. The lift exerted by an airplane wing is caused by air rushing over the top of the wing at greater speed (thus reducing the pressure there) than it moves by the under side. See Fig. 202. To demonstrate how this produces lift, blow a steady stream of air over a sheet of paper held as shown in Fig. 203.

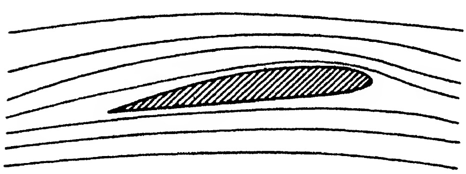

FIG. 202. AIR FOIL.

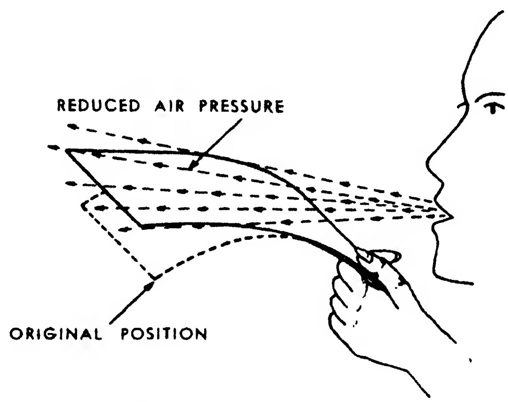

FIG. 203. THEORY OF LIFT.

3. The "venturi" in a carburetor applies Bournoulli's Principle. Fig. 204 shows a cross-sectional view of a modern automobile carburetor. The venturi tubes cause the fuel-air mixture to move more rapidly, reducing the pressure. This causes the gasoline to evaporate more rapidly and vaporize more completely.

OPERATION OF THE MODERN DOWN-DRAFT CARBURETOR

The carburetor is a complicated piece of precision built machinery. With the aid of Fig. 204, the following description will explain its operation. This carburetor has three venturis, one located above and two below the level of the fuel in the float chamber. The triple venturi increases the suction on the first or primary venturi, causing the nozzle to start delivering fuel at very low air speeds.

STARTING

With the choke valve closed, suction from the down stroke of the piston draws a small amount of air past it. This air is then mixed with gasoline drawn from the main nozzle, forming a rich mixture for easy starting.

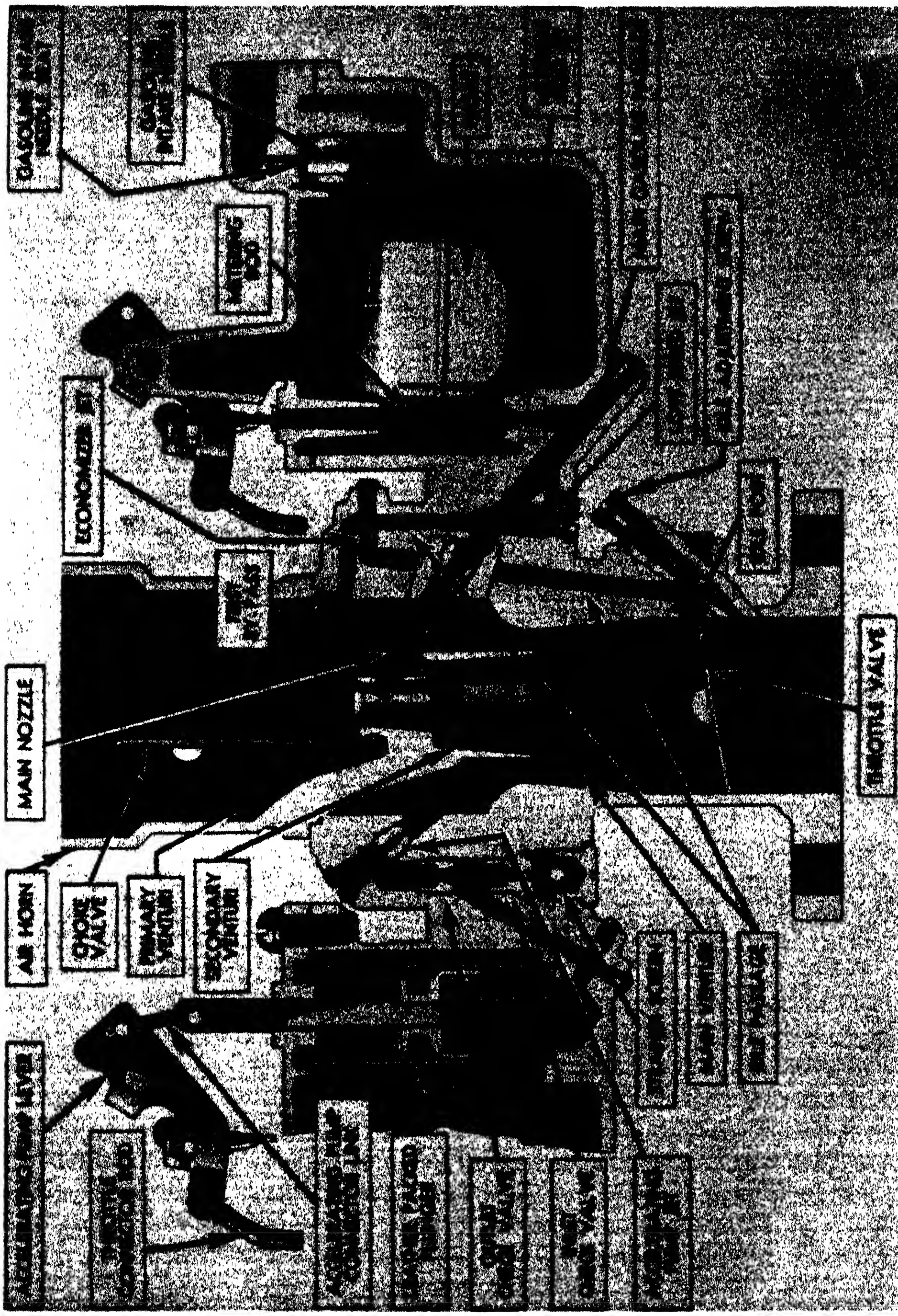

FIG. 204. DIAGRAMMATIC VIEW OF CARBURETOR.
(Courtesy, General Motors Corp., Chevrolet Division)

IDLING

At idling speed the throttle is closed and the suction from the down stroke of the piston is concentrated on the idling port below the throttle valve. This suction is applied to the low speed passage in the carburetor

body and results in air being drawn in through the by-pass hole in the carburetor body. The air is then swept over the top of the low speed jet, lifting gasoline from the jet. The gasoline and air mixture then passes through the economizer and down the idler passage to the idling ports, where it is discharged into the throat of the carburetor and then through the manifold to the cylinders. As the throttle valve is opened, the idling port above the throttle valve is uncovered, increasing the suction on the idling system, thus permitting it to furnish the necessary fuel mixture for the increase in speed.

LOW SPEED

With the throttle partly open, suction from the down stroke of the piston draws air in through the air horn. The air passing through the main venturi increases in velocity (Bernoulli's principle) with the result that the suction is increased over the secondary venturi. This increased air speed, through the secondary venturi, in turn steps up the suction on the primary venturi. The air passing through the primary venturi, draws gasoline from the main nozzle, where it is mixed with the air passing through the primary, secondary and main venturi, forming a finely atomized mixture which then passes to the manifold and cylinders.

HIGH SPEED

The operation at high speed is similar to that at low speed except the metering rod is raised to increase the size of the jet and furnish additional gasoline for high speeds and wide open throttle operation.

FORCES

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 167-215.
Dull: *Modern Physics*, pages 107-160.
Fletcher: *Unified Physics*, pages 79-128.
Holley and Lohr: *Mastery Units in Physics*, pages 135-159.
Millikan: *New Elementary Physics*, pages 83-128.
Smith: *Mechanics*, pages 23-76.
War Department —
TM-565 *Automotive Brakes*, pages 24-28.

FORCE

A force is commonly defined as a "push or a pull." A force acting on a body at rest, tends to make it move and a force acting on a moving body, tends to change its velocity, direction, size or shape. Force is measured in pounds or grams. A force has magnitude (in pounds or grams) and direction, with a designated point of application. Such forces are represented by "vectors." A vector is represented graphically by a straight line, drawn in a given direction, its length (to any scale) represents the magnitude of the force, the arrow, its direction and point of application. See Fig. 205.

The gravitational pull of the earth is the most common force. There is a mutual attraction between any two bodies in the universe. The gravitational effect of the moon causes tides in the ocean waters of the earth. Sir Isaac Newton is credited with being the first to correctly state the

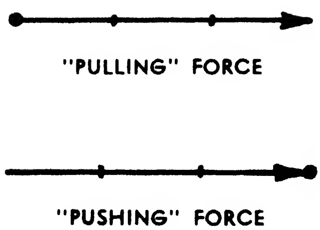

FIG. 205. VECTORS.

FIG. 206. A WHEEL WRENCH IS A "COUPLE."

"Law of Gravitation." This law states that the attraction between two bodies is directly proportional to their masses and inversely proportional to the square of the distance between their centers. The mutual attraction between the earth and bodies on or near the earth is called "gravity." The measure of the pull of gravity on a body is known as its weight.

COMPOSITION OF FORCES

Forces acting in the same plane upon a body can be classified in three groups, namely:

1. Forces acting in the same straight line, either in the same or opposite directions. Since their directions coincide, they are commonly known as "coincident forces."
2. Forces acting on a body at a point but at an angle to each other, known as "concurrent forces."
3. Forces which do not meet but act in directions parallel to each other. These are known as "parallel forces." Such forces may be in equilibrium with each other, as when the sum of the forces acting in one direction equals the sum of the forces acting in the opposite direction. If acting in opposite directions at separate points they will cause rotation, such forces constituting a "couple." Fig. 206 shows a tool which utilizes the principle of the "couple."

A single force, called the resultant, may be substituted for two or more forces acting at a single point. The resultant of coincident forces, if acting in the same direction, will be their sum; if acting in opposite directions, their difference.

The resultant of concurrent forces may be found graphically by the "parallelogram" law; or may be solved algebraically. It is neither the sum or difference of the two forces.

A force which prevents a single force, or a group of forces from moving a body is known as the "equilibrant." The equilibrant is equal in size and opposite in direction to the resultant. The process of finding the re-

sultant of two or more forces is known as the "composition of forces."

Often, when two or more forces act at a point, the magnitude of only one is known. If the directions in which the other forces act are known, their magnitude may be determined graphically or algebraically by reversing the process of finding the resultant. This is known as the "resolution of forces." It is well to know also, that velocities may be dealt with in exactly the same manner as forces. To illustrate the preceding discussion of forces, a series of experiments and demonstrations will now be performed.

COINCIDENT FORCES

Demonstration:

The forces acting on a tow rope attached to two cars or on the draw bar of a railroad car illustrate two of many common examples of coincident forces. The resultant of such forces is determined by their magnitude and direction. It can be illustrated clearly by making use of a single fixed pulley and a few weights. In doing this it should be recalled that the M. A. of such a pulley system is one, the pulley merely changing the direction in which the force acts.

Arrange three single pulleys with the weight combinations as shown

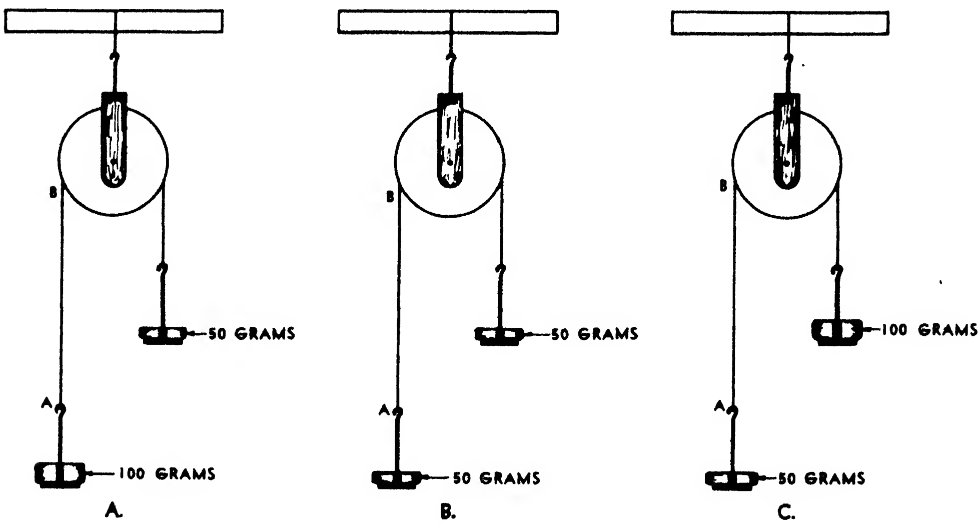

FIG. 207. COINCIDENT FORCES.

in Fig. 207 A, B and C. Considering the coincident forces acting on the string AB, what is the magnitude and direction of the resultant of the forces acting in (A)? .... in (B)? ....

.... In (C)? ....

CONCURRENT FORCES

Purpose:

1. To find, graphically, the resultant of two or more forces acting at

a single point on a body at various angles to each other. "The "composition of forces."

2. To resolve a single force graphically, into two forces acting at an angle to each other. The "resolution of forces."

3. To check each of the foregoing graphic solutions, algebraically.

Tools and Materials:

Three spring balances
Strong cord string
Three string clamps

Note: If a force table is available it may be used in place of this material.

Small, rectangular block of wood
Inclined plane board
Weight hanger and set of slotted weights
Heavy roller (or a weighted Hall's carriage)
Two single pulleys
Protractor

Introduction:

Since the resultant of concurrent forces is determined graphically by means of a parallelogram, some needed geometrical facts concerning parallelograms are necessary —

a) A parallelogram is a four sided, plane figure, the opposite sides of which are equal and parallel

b) The diagonal of a parallelogram divides it into two equal triangles. (Equal triangles have corresponding sides of the same length and corresponding angles of the same number of degrees.)

Note: It is assumed that the student understands the use of a protractor in constructing angles; also the use of a pencil compass in constructing one angle, or one line, equal to a given angle or line. If not, ask the instructor to explain these operations.

As previously explained, forces or velocities are represented by vectors. In determining forces graphically, extreme care must be taken to be neat and accurate. The following suggestions will aid the student in achieving accuracy in making graphs:

1. Use a well sharpened pencil with fairly hard lead. Use light lines.
2. Use a ruler with a straight edge.
3. Use a well sharpened pencil compass for completing a parallelogram.
4. In drawing the vectors, use as large a scale as possible. This will decrease the possibility of errors.
5. When the diagram is completed, label it fully, being sure to indicate the scale used.

COMPOSITION OF FORCES

Procedure:

a) Fasten two spring balances to one side of a table and one balance to the opposite side by means of string clamps. Fasten a strong string to the balances as shown in Fig. 208, exerting enough force on the string to cause the balances to show a large reading. (This will give greater accuracy). Lay a piece of blank paper beneath the junction of the three strings, then place a wooden block along side each string and make a

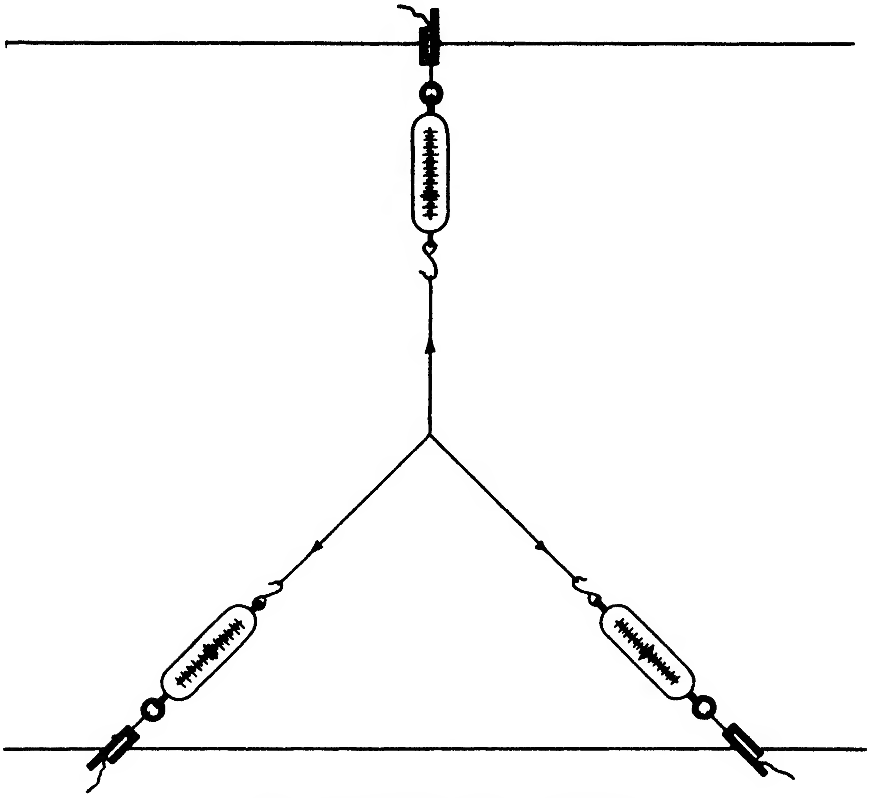

FIG. 208. COMPOSITION OF FORCES.

fine line on the paper to represent each string. Be exact and do not change the direction of the string by shoving the block too tightly against it. Record the balance reading on each line.

Remove the paper and continue the lines until they meet at a point. Select any two of the lines, and using a convenient scale complete the construction of the parallelogram. If accurately done, this diagonal will form

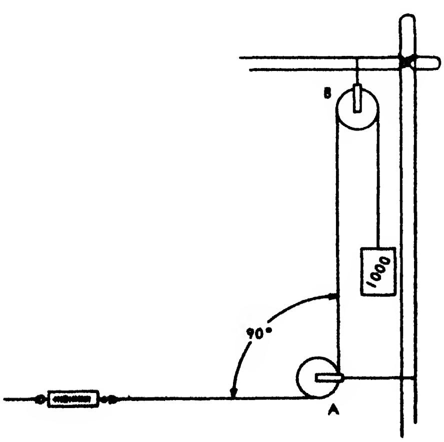

FIG. 209. FORCES AT 90° ANGLE

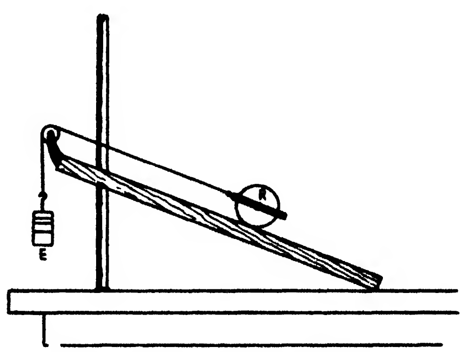

FIG. 210. INCLINED PLANE.

a straight line with the third force (the equilibrant). Measure the length of the diagonal and compute to scale, its force value. How does this value compare with the balance reading representing the third force? ....

....

b) Arrange two single pulleys for lifting a weight as shown in Fig. 209. Determine how much force will be needed to lift a 1000 g. weight when pulling horizontally on the spring balance. Make a drawing, to scale, showing the size and direction of the force exerted by the pulley A.

RESOLUTION OF A FORCE

Set up an inclined plane and determine how much force is exerted by a spring balance (or weight) in holding a heavy roller stationary in the middle of the plane. (See Fig. 210.) Measure accurately the angle the inclined plane makes with the horizontal.

Balance reading .... Angle of plane ....

TABLE XLVII

The three forces acting on the roller are shown in Fig. 211. Determine

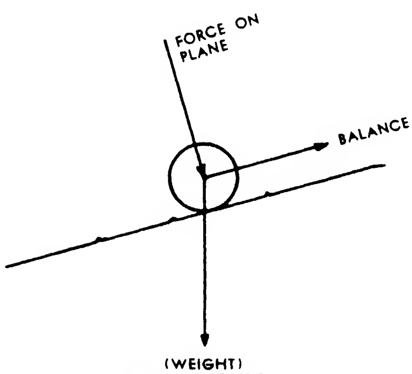

FIG. 211. FORCES ACTING ON AN INCLINED PLANE.

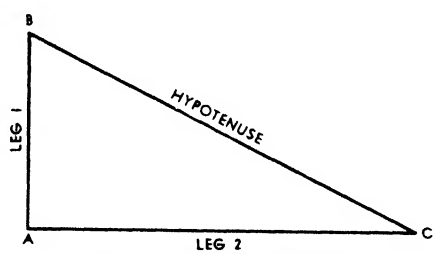

FIG. 212. RIGHT TRIANGLE.

the size of the force pushing against the plane, also the weight of the roller, by making a force diagram (to scale). Weigh the roller and compare with the calculated weight.

Actual weight .... Calculated weight ....

TABLE XLVIII

Algebraic solutions

Force problems may be solved by applying algebraic and trigonometric formulas. A few of the fundamentals can be briefly stated.

a) If the forces are acting at right angles to each other, the right triangle formula is used, thus:

$$\overline{\text{Hyp}}^2 = (\text{Leg } 1)^2 + (\text{Leg } 2))^2$$

or

$$\overline{BC}^2 = \overline{AB}^2 + \overline{AC}^2$$

Example:

Find the resultant of two forces, one of 10 lb. acting East and one of 4 lb. acting North.

Solution:

$$\overline{OX}^2 = \overline{OE}^2 + \overline{EX}^2$$

$$= 10^2 + 4^2 = 100 + 16 = 116$$

$$\text{Resultant OX} = \sqrt{116} = 10.78 \text{ lb. acting NE.}$$

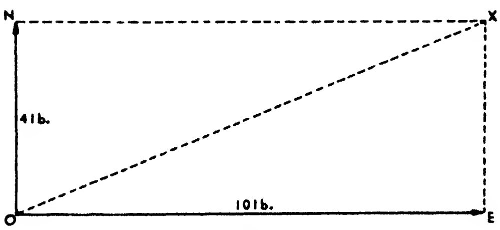

FIG. 213.

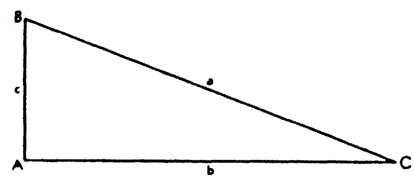

FIG. 214 TRIGONOMETRIC FUNCTIONS.

Trigonometry deals with the relations between the sides and angles of a right triangle. The study of trigonometry is a complete course in mathematics, hence just that part which is useful in the solution of simple problems will be given here. The following three trigonometric functions should be mastered.

$$\text{Sine} = \frac{\text{opposite side}}{\text{hypotenuse}}$$

$$\text{Cosine} = \frac{\text{adjacent side}}{\text{hypotenuse}}$$

$$\text{Tangent} = \frac{\text{opposite side}}{\text{adjacent side}}$$

For angle C, Fig. 214 these relations become:

$$\text{Sin} \angle C = \frac{c}{a}$$

$$\text{Cos} \angle C = \frac{b}{a}$$

$$\text{Tan} \angle C = \frac{c}{b}$$

Example:

A 20 foot ladder is leaned against the side of a house. If it makes a 60° angle with the ground, how high above the ground is the top of the ladder. See Fig. 215.

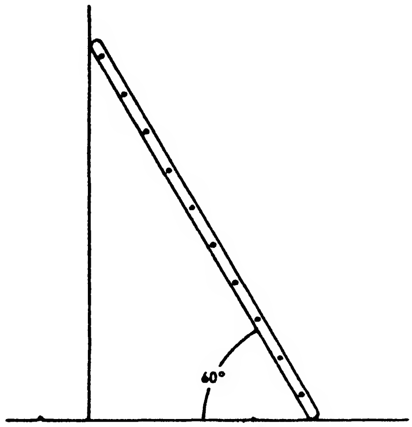

FIG. 215. LADDER PROBLEM.

Solution:

$$\text{Sin } 60^\circ = \frac{X}{20} \quad \left(\frac{\text{opposite side}}{\text{hypotenuse}}\right)$$

$$.866^* = \frac{X}{20}$$

$$X = 17.32 \text{ feet}$$

* Sin 60° = .866 as obtained from a table of trigonometric functions.

Since many triangles are not right triangles, their solution is more complicated. The "Law of Sines" may be used in their solution. This law states that in any triangle, the sides are to each other as the sines of the opposite angles. Referring to Fig. 214 this can be written:

$$\frac{a}{\text{Sin A}} = \frac{b}{\text{Sin B}} = \frac{c}{\text{Sin C}}$$

Example:

A crane boom AB, Fig. 216, exerts a compression force of 600 lb. in lifting the weight W. What is the tension force in the cable CB?

Solution:

$$\frac{\text{Sin } \angle A}{CB} = \frac{\text{Sin } \angle C}{AB}$$

$$\frac{\text{Sin } 45^\circ}{CB} = \frac{\text{Sin } 120^\circ}{600}$$

$$\frac{.707}{CB} = \frac{.866^*}{600}$$

$$.866\ CB = 424.2$$

$$CB = \frac{424.2}{.866}$$

$$= 489 \text{ lb.}$$

* The Sin 120° is the same as the Sin 60°. Check the graphic solution in this experiment algebraically, if time permits.

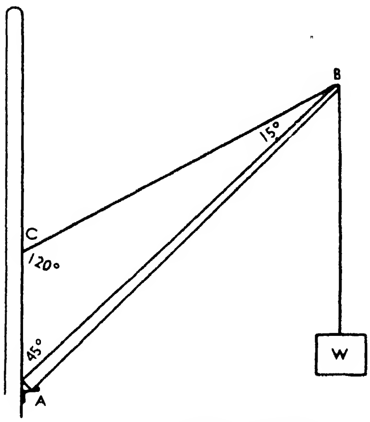

FIG. 216. CRANE BOOM.

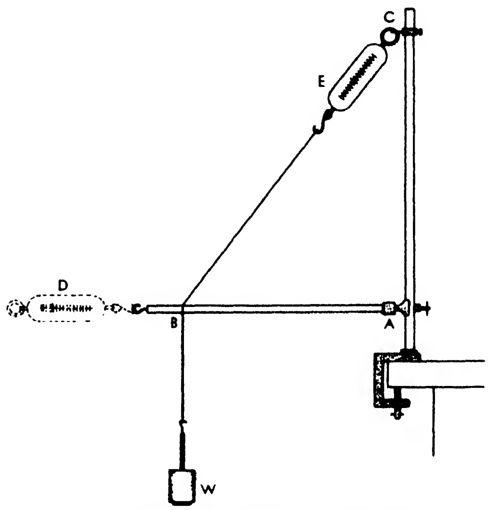

FIG. 217. DERRICK BOOM (HORIZONTAL).

THE SIMPLE DERRICK

Purpose:

To find the tension in the cable and compression in the boom of a simple derrick.

Tools and Materials:

Simple derrick truss
Two spring balances (2000 g.)
Weight and weight hanger
Protractor and ruler
Heavy cord string

Procedure:

a) With boom horizontal

Set up the derrick as shown in Fig. 217. Add weights to the weight hanger until balance E nearly reaches its full scale reading. Keep the boom AB horizontal. Balance E measures the tension in cable CB. Measure the compression in the boom AB by placing a balance in position D pulling horizontally until the boom just moves away from its support.

Note: the balances are used in this experiment merely to check the graphic and algebraic solutions.

With a protractor, accurately measure angle ABC.

Weight (W) .... Angle ABC ....

Tension in CB (balance reading E) ....

Compression in AB (balance reading D) ....

TABLE XLIX

Find the tension and compression forces in the derrick by the graphic method (resolution of forces). To do this proceed as follows:

1. On a sheet of unruled paper construct an angle equal to ∠ABC.
2. Using a convenient scale draw the vector BW (the equilibrant).
3. Continue BW vertically upward (the resultant) to equal the equilibrant.
4. Construct a parallelogram on the resultant.
5. Measure the sides of the parallelogram which represent the tension and compression forces. Write the value of these forces on the diagram.

How do these values compare with the balance readings?

....

Using the right-triangle formula, calculate the tension and compression forces algebraically.

b) With boom at an angle to the horizontal

Set up the derrick with the boom as shown in Fig. 218. Repeat the experiment as performed in part (a). Draw parallelogram to determine the tension and compression forces in the derrick.

Weight (W) ....

Angle ABC ....

Tension in CB (balance reading E) ......

....

Compression AB (balance reading D)

....

TABLE L

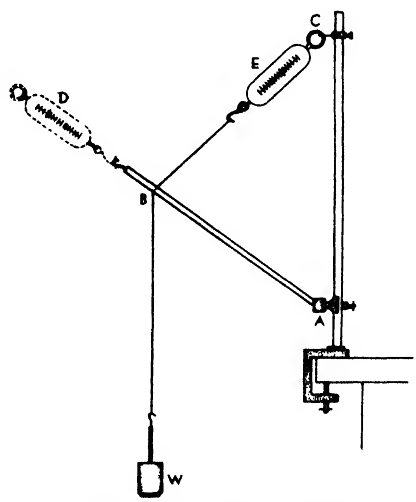

FIG. 218. DERRICK BOOM (AT AN ANGLE).

Using the "Law of Sines" compute the tension and compression forces.

How do the computed tension and compression forces compare with balance readings? ....

THE ROOF TRUSS

Purpose:

To measure the compression in the rafters and the tension in the tie-beam of a simple roof truss.

Tools and Materials:

Roof truss model
Two spring balances (30 lb. capacity)
Weight (about 25 lbs.)
Protractor and rule

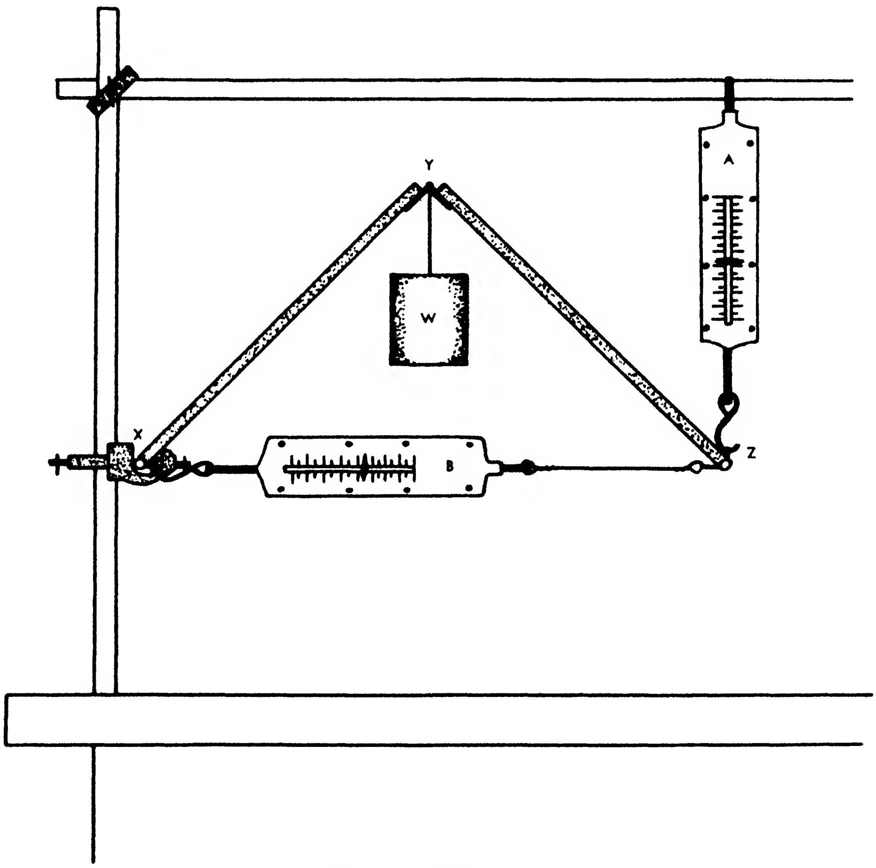

FIG. 219. ROOF TRUSS.

Procedure:

Set up a model roof truss as shown in Fig. 219. One half the weight of each rafter acts vertical downward at its ends, therefore the weight acting downward at Y is (W + ½ the weight of the truss.)

What kind of a force is exerted in the rafters XY and YZ? ....
.... In the tie beam XZ? ....

As in previous experiments, the balance readings are used to check the computations. Measure angles XYW and ZYW with a protractor.

Weight .... Angle XYW .... Angle ZYW........................

Balance reading A (vertical) .... Balance reading B (horizontal) ....

TABLE LI

On a full sheet of paper make a graphical solution of the compression force in the rafter and the tension force in the tie beam. Proceed as follows:

1. Draw a vertical line YW (to scale) representing the weight on the truss. (W + $\frac{1}{2}$ weight of truss.)
2. At the top of YW construct angles equal to $\angle$XYW and $\angle$ZYW.
3. Using YW as the resultant construct a parallelogram.
4. Measure XY and compute the compression force in the rafter. Write this value on the diagram.
5. Using XY as the resultant of the vertical and horizontal forces, construct another parallelogram. Measure the horizontal vector in this parallelogram and compute the tension in the tie rafter.
6. Measure the vertical vector in the parallelogram, compute its value, and compare it with the vertical balance reading (A) (be sure to add $\frac{1}{2}$ the weight of rafter XY to your vector value before comparing with the balance reading).

How do the graphic values compare with the balance readings A and B?

....

....

Questions and Problems:

1. A force is a .... or a .... which acts on a body to

   ....

   ....

2. Forces are represented graphically by straight lines called ....

   .... A vector has ...., ...

   and ....

3. What is the "Law of Universal Gravitation"? ....

   ....

4. Gravity is the mutual attraction between ....

   ....

5. Weight is the measure of ....

   ....

6. Coincident forces act ....
while concurrent forces act ....
....
7. A single force which has the same effect as two or more forces is called the .... force.
8. An equilibrant force is ....
9. Using the parallelogram method, find the ground speed and direction of flight of an airplane traveling 100 M. P. H. (air speed) eastward when the wind is blowing south-east at 20 M. P. H.

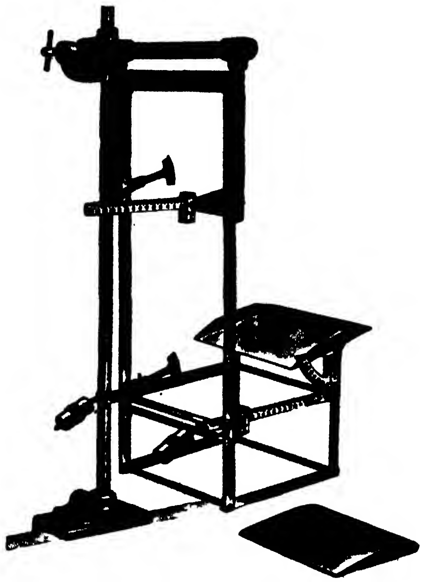

FIG. 220. AIRPLANE FORCE APPARATUS. (Courtesy, Central Scientific Co.)

Fig. 220 shows a laboratory model airfoil and wind tunnel used for measuring the lift and drag on various types of airfoils at different angles of attack.

The effect of the air moving past the airfoil may be resolved into two forces, one perpendicular to the direction of the air stream and *approxim-*

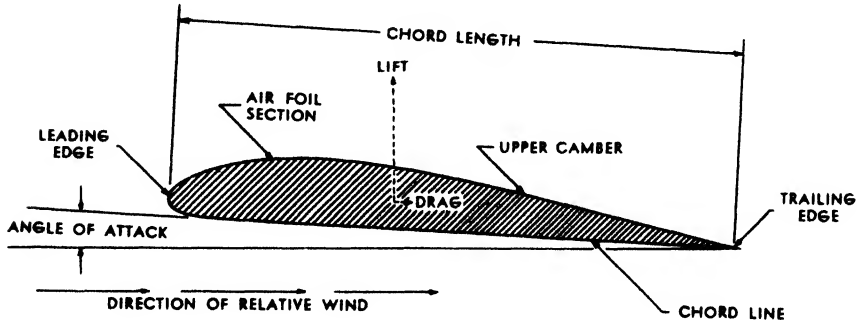

FIG. 221. AIRFOIL.

ately perpendicular to the surface of the airfoil; the other parallel to the air stream. The perpendicular force is called "lift"; the force parallel to the air current is called "drag." (See Fig. 73.) Fig. 221 gives the terms pertaining to an airfoil in horizontal flight.

10. Draw a diagram showing the lift and drag on an airplane wing with a 10° angle of attack. The plane weighs one ton and the drag is half the weight. Also find the resultant of these forces.

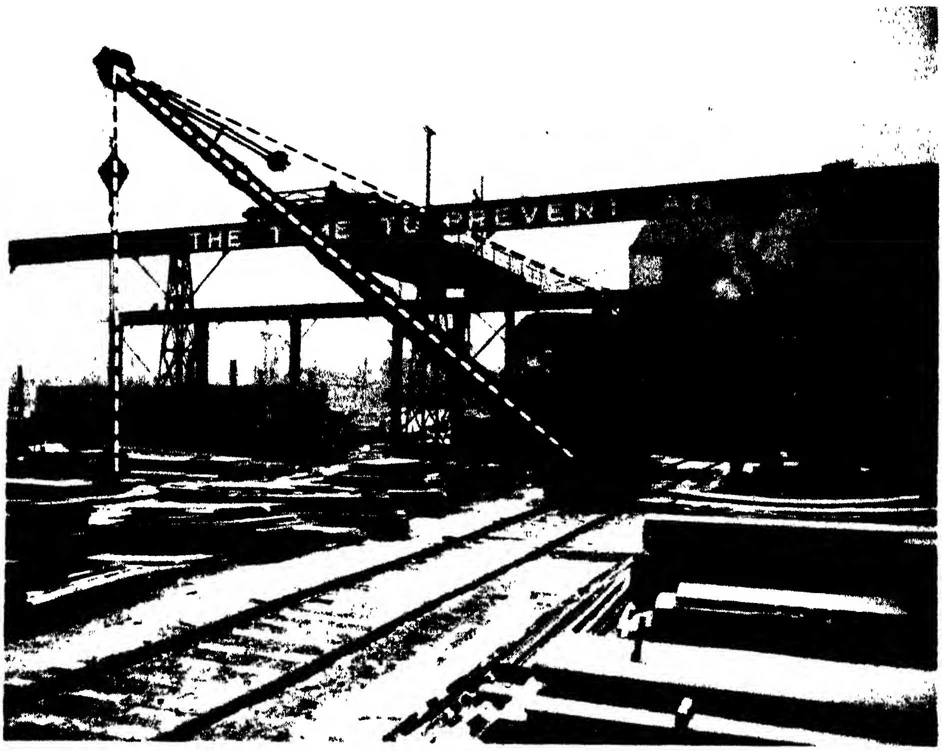

FIG. 222. RAILROAD DERRICK.

11. Shown in Fig. 222 is a small railroad derrick. The vertical cable is lifting a 2 ton weight. Find the compression on the boom and the tension on the upper cable, using the graphic method of solving. (Use a full sheet of paper). Disregard the weight of the boom.

TRUSSES

A truss is a rigid framework made by joining a system of beams, bars or rods, by welding or riveting. Since there is a great variety of trusses in use, only a few will be discussed here. It will be noticed that trusses usually are combinations of triangles. The triangular shape is used because it is the only geometric figure that cannot change its shape without changing the length of its sides.

ROOF TRUSSES

Aside from the simple triangular roof truss, as used in the previous experiment, other standard designs are used for longer spans. The Pratt and Triangular trusses are illustrated in Fig. 223. Observe that compression members are made much heavier than tension members.

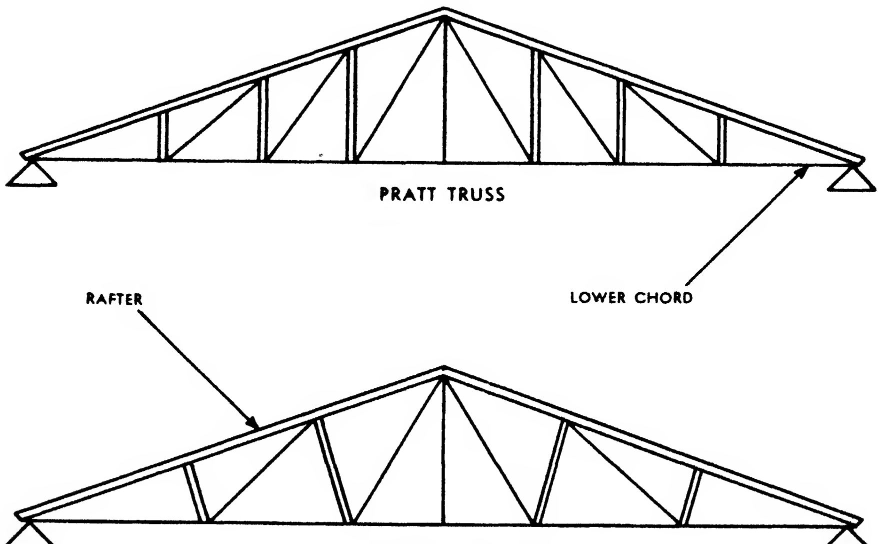

FIG. 223. PRATT AND TRIANGULAR ROOF TRUSS.

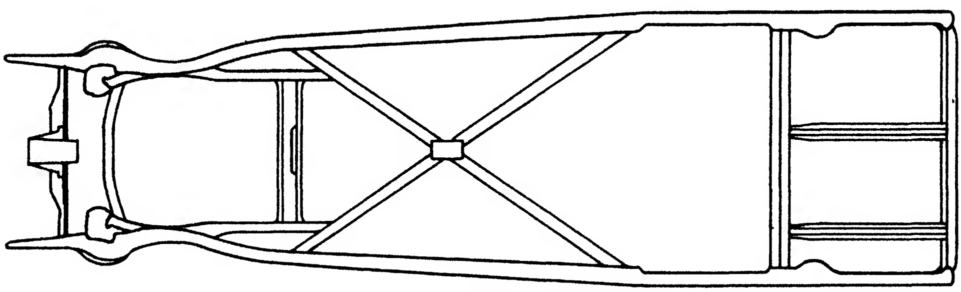

FIG. 224. AUTOMOBILE FRAME.

THE AUTOMOBILE FRAME

Shown in Fig. 224 is a typical automobile frame. The side members of the frame are made of channel steel (Fig. 225A) and the X member is of I-beam construction (Fig. 225B). The frame is so designed as to allow spring action and wheel turning with the greatest freedom. The side pieces are made of varying widths, and the cross members often have holes punched in them so as to lighten the frame as much as possible without dangerously weakening the frame.

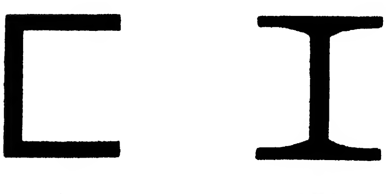

FIG. 225. CHANNEL AND I-BEAM.

THE AIRPLANE WING AND FUSELAGE

Triangular truss construction is widely used in airplane wing and fuselage construction. See Fig. 226 A and B.

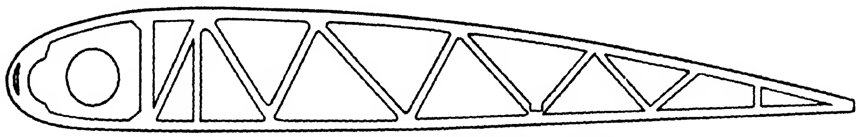

FIG. 226A. TRUSS WING CONSTRUCTION.

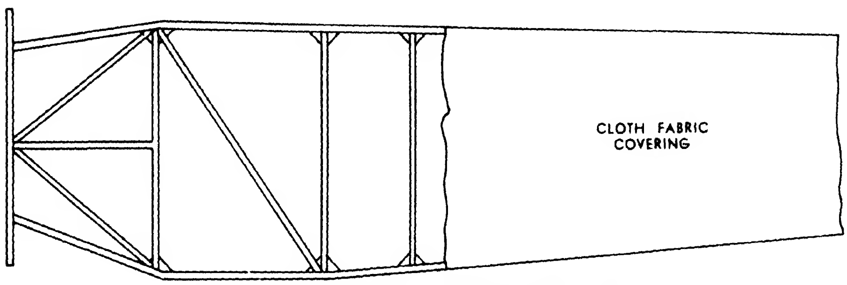

FIG. 226B. TRUSS FUSELAGE CONSTRUCTION.

PARALLEL FORCES IN EQUILIBRIUM

Purpose:

To show that a body acted upon by parallel forces will be in equilibrium when:

a) The sum of the forces acting in one direction equal the sum of the forces acting in the opposite direction.

b) The sum of the clockwise moments equals the sum of the counterclockwise moments.

Tools and Materials:

Uniform wooden or steel bar	Weights and strong cord
Two spring balances (2000 g.)	Meter stick

Procedure:

After locating the center of gravity and determining the weight of the bar, set up the apparatus as shown in Fig. 227. Suspend a heavy weight a short distance from one of the balances and adjust the height of the balances so that the bar hangs horizontal. Read the balances, then in the follownig space make a force diagram, clearly labelling the size of the forces acting, their direction of action and their location on the bar.

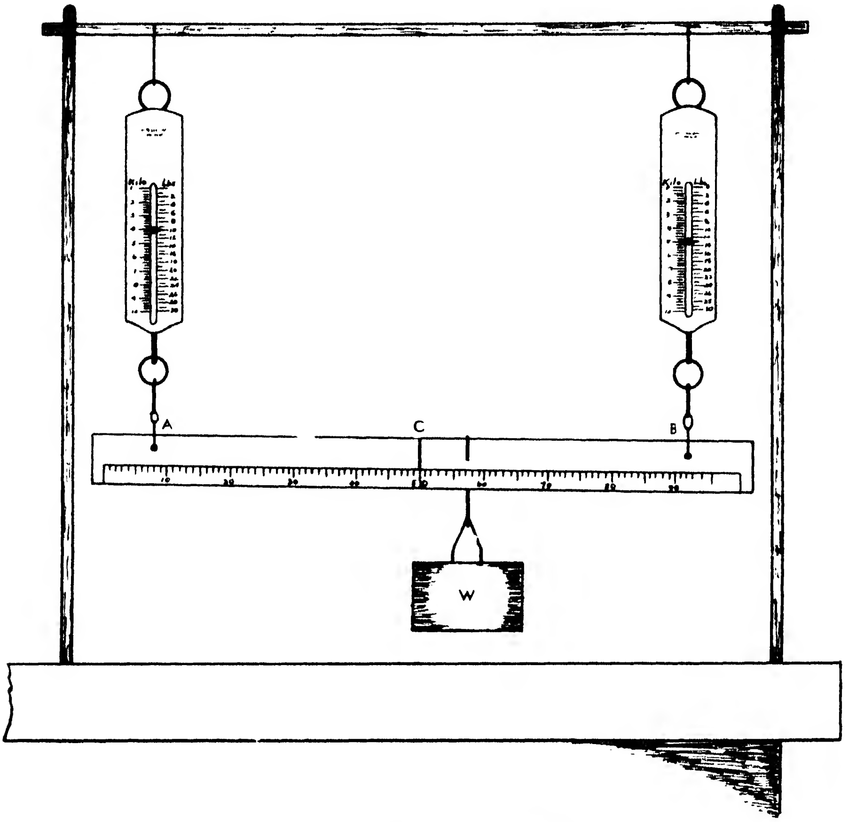

FIG. 227. PARALLEL FORCES.

Tabulate the results in Table LII.

	Forces Acting		*Moments around A*		*Moments around C*	
At	*Up*	*Down*	*Clockwise*	*Counterclockwise*	*Clockwise*	*Counterclockwise*
A						
B						
C						
W						
Total						

TABLE LII

Questions and Problems:

1. In Table LII how do the sums of the upward and downward forces compare? ....

   The sums of the clockwise and counterclockwise moments? ....

   ....

Explain any difference that might occur ....

....

2. Find the weight supported by the front and rear wheels of a cai weighing 2700 pounds, using the dimensions given in Fig. 228.

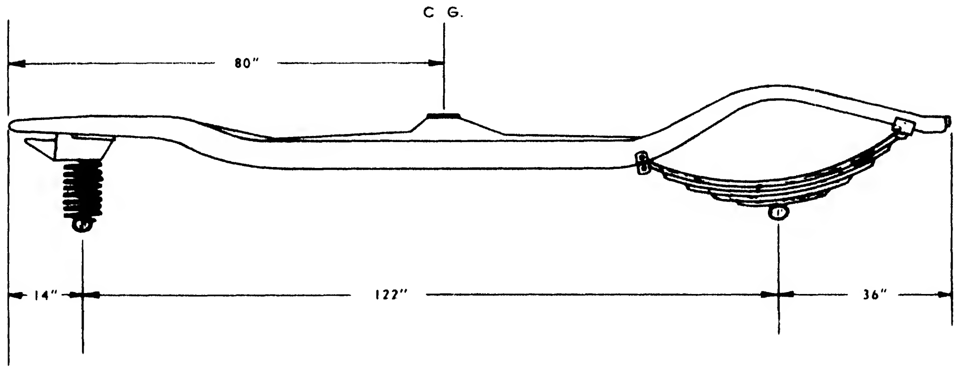

FIG. 228. AUTO FRAME AND PARALLEL FORCES.

3. In many states, the weight of a truck is determined by the use of portable scales. To use, the front wheels are run onto the scales and weighed, then the rear wheels are weighed in the same manner. How can the weight of the truck be determined by this procedure? ....

....

....

4. A painters' scaffold 16 feet long is suspended on two sets of block and tackle. The scaffold is uniform and weighs 75 pounds. A man weighing 150 pounds stands 4 feet from one end of the scaffold. Make a force diagram and calculate the weight supported by each rope.

5. A bridge is 200 feet long between the supporting piers. A 10 ton truck stops 50 feet from one end of the bridge. Make a diagram and calculate what part of this weight each pier supports.

TYPES OF MOTION

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 187-203
Dull: *Modern Physics*, pages 135-141.
Fletcher: *Unified Physics*, pages 79-99.
Holley & Lohr: *Mastery Units in Physics*, pages 168-194.
Millikan: *New Elementary Physics*, pages 105-113.
War Department —
TM 10-565 *Automotive Brakes*, pages 3-10.

DEFINITION OF MOTION

Motion may be defined as a change in location of a body due to an external force acting during a unit of time. Motion is the result of a force doing work on a body. The motion of a body may be uniform or variable. In uniform motion the space passed over in an interval of time (minute, second, etc.) is the same for each succeeding interval. In variable motion a different amount of space is passed over each succeeding interval of time.

The motion of a body is usually expressed as a definite distance (such as inches, feet, yards, miles, etc.) passed over in an interval of 1 second, 1 minute, or 1 hour. If an airplane flies over a distance of 500 miles in 5 hours, its average speed or velocity is $\frac{500 \text{ miles}}{5 \text{ hours}}$ or 100 miles per hour (M.P.H.) This is an average velocity because the plane started from rest and gained in speed to a maximum then slowed down to a stop. At any one instant it may have been flying faster or slower than 100 miles per hour.

In Table LIII, change the velocities from M.P.H. to feet per second. (Hint: 15 miles per hour is 22 feet per second.)

	Common Velocities	
	Miles per hour	*Feet per second*
Fast walking	5	
Running	15	
Automobile	60	
Airplane	300	
Pistol bullet	600	
Army rifle bullet	1800	

TABLE LIII

In general

$$\text{Average Velocity} = \frac{\text{Total distance}}{\text{Total time}}$$

$$v = \frac{s}{t}$$

and

$$\text{Distance covered} = \text{Average velocity} \times \text{time}$$

$$s = vt$$

Problems:

1. What is the average velocity (M.P.H.) of an automobile which goes a distance of 100 miles in $2\frac{1}{2}$ hours? How many feet per second is this?

2. The average velocity of a rifle bullet is 2000 ft. per second. If the target is 500 ft. away, how long is the bullet in flight?

CUTTING SPEED

In the shop it is necessary for the machinist to adjust the cutting speed of machine tools to prevent damage due to excessive frictional heat at the tool bit and to prevent overload on the machine itself. The cutting speed is the velocity with which a cutting tool moves over the work.

In the case of a planer or shaper, where the tool is moving forward and backward, the length of the stroke in feet, times the number of strokes per minute, is the cutting speed.

In a lathe, the work is revolving and the tool is stationary, the cutting speed depends on the number of revolutions per minute and the diameter of the piece.

$$\text{Cutting speed} = \frac{\pi \times \text{diameter in inches} \times \text{rpm}}{12}$$

Example:

A 2″ axle is turned at the rate of 100 revolutions per minute. The cutting speed is:

$$\text{Cutting speed} = \frac{3.14 \times 2 \times 100}{12} = 52.3 \text{ ft./min.}$$

Problems:

1. A cutting speed of 100 ft. per minute is desired when turning a piece of work whose average diameter is 4 inches. At what speed must the work rotate?

2. A surface plate, 2 by 3 feet is being planed at a cutting speed of 10 ft. per minute. If the width of the cut is $\frac{1}{4}''$, how long will it take to plane the plate?

ACCELERATION

A) First Law

A well known company advertises that its automobile has a "pick up" that will enable it to attain a speed of 30 miles per hour in 5 seconds, from a standing start. This means a gain in velocity of 6 miles per hour per second.

$$\frac{\text{30 miles per hr.}}{\text{5 sec.}} = \text{6 miles per hour per second)}$$

Expressed in feet, 30 miles per hour is 44 ft. sec.

$$\text{therefore} \quad \frac{\text{44 ft. per sec.}}{\text{5 seconds}} = \text{8.8 feet per sec. per sec.}$$

(or 8.8 ft./sec^2). This is an acceleration or a gain in velocity for each second over the previous second.

The final velocity of a body under constant acceleration is the gain in velocity for each second (acceleration) times the number of seconds in motion.

$$v = a\,t$$

$$\text{Final Velocity } (v) = \text{acceleration } (a) \times \text{time } (t)$$

FIRST LAW OF ACCELERATION

If the acceleration is constant, the velocity attained is directly proportional to the time elapsed.

B) Second Law

The space passed over is found by:

$$\text{Distance} = \text{average velocity} \times \text{time}$$

$$s = vt$$

$$\text{Average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

For bodies starting at rest and uniformly accelerating, the formula becomes

$$\text{Average velocity } (v) = \frac{0 + v}{2} = \tfrac{1}{2}\,v = \tfrac{1}{2}\,at$$

Therefore distance passed over is

$$s = vt$$

$$\text{Since } v = \tfrac{1}{2}\,at$$

$$\text{then } s = \tfrac{1}{2}\,at \times t$$

$$s = \tfrac{1}{2}\,at^2$$

SECOND LAW OF ACCELERATION

If the acceleration is constant, the space covered is directly proportional to the square of the time elapsed.

C) Third Law

The third law of acceleration may be derived from the second.

$$s = \tfrac{1}{2} at^2$$

$$\text{and} \quad t = \frac{v}{a} \quad \text{(first law)}$$

$$\text{substituting} \quad s = \tfrac{1}{2} a \frac{(v)^2}{(a)^2}$$

$$\text{then } s = \frac{v^2}{2a}$$

$$\text{and} \quad v^2 = 2as$$

$$v = \sqrt{2as}$$

THIRD LAW OF ACCELERATION

If a body starts from rest and the acceleration is constant, the velocity varies as the square root of the distance covered.

Demonstration:

Set up a long grooved board marked into 16 equal parts. Fig. 229.

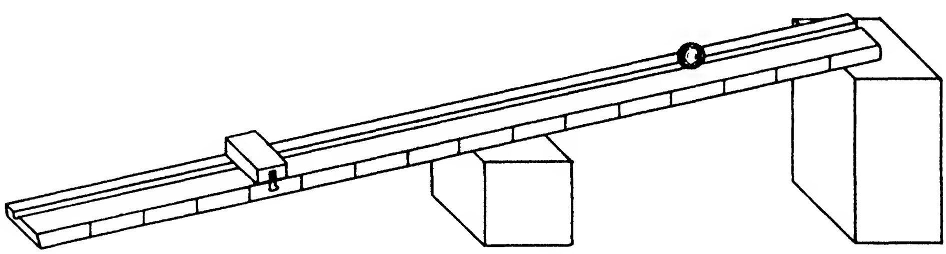

FIG. 229. ACCELERATION APPARATUS.

Elevate one end of the board so that a large ball bearing will roll the entire length in exactly 4 seconds.

Place the ball at the upper end and allow it to roll, observing its position at the end of the first second. Make several trials.

Repeat the procedure and locate the position for the second, third and fourth second. Measure each position in units from the upper end and record in Table LIV.

First second	....	(units)	....	inches
Second second	....	"	....	"
Third second	....	"	....	"
Fourth second	....	"	....	"

TABLE LIV

1. How does the distance (in units of 16) compare with the time? ....

....

2. Using a formula from the preceding discussion, find the following: The acceleration of the ball .... The velocity of the ball as it reached the end of the board .... Distance covered in the 1st. second ....; 2nd. second ....; 3rd. second ....; 4th. second ....
3. A bomber is flying at an altitude of 20,000 feet and at a speed of 300 miles per hour. How long will it take a bomb to reach the ground from the plane? How far will the plane fly while the bomb is dropping?

4. An engine is running 1800 R.P.M. If the length of the piston stroke is 6 inches, what is the average velocity of the piston in feet per second? In miles per hour?

NEWTON'S LAW OF MOTION

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 201-231.
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INERTIA

Sir Isaac Newton discovered three laws of motion as a result of his studies of forces acting on a body moving through space. Each of these laws will be studied by considering some familiar examples.

The *first law of motion*, sometimes called the law of inertia, is as follows: "A body at rest tends to remain at rest and a body in motion tends to remain in motion in a straight line, unless acted upon by an outside force." A mass of matter does not possess the ability to set itself in motion or to stop its motion if already in motion. Bodies remain at rest because of 1) a stable equilibrium, 2) adhesive and cohesive forces holding them still, and 3) static friction preventing their movement. That a body at rest tends to remain at rest is further evidenced by one's experience in trying to push a heavy box or move a stalled automobile.

A body may be moved, provided an external force is applied which is great enough to overcome friction or other forces tending to keep it at rest. When the resultant of all forces acting on a moving body is zero, the

body continues in uniform motion. When the forces acting on a body become unbalanced, the body either slows up, increases its speed, or changes its direction of motion.

Inertia is put to practical use in many ways. The hammer drives nails and the sledge forges metal because of the inertia of the moving head. The axe and whirling circular saw "bite" into wood, driven forward by their inertia. The flywheel of an engine smooths out it's operation, preventing a jerky motion from the separate power impulses. The great inertia of a rotating flywheel causes the punch of a punch press to pierce thick metal; or the jaws of the forging machine to shape hot metal.

Demonstration:

a) Suspend a heavy weight by a piece of linen thread as shown in Fig. 230. Tie a second piece of thread to the bottom of the weight.

Pull downward gradually on the bottom thread until one of the threads break.

Which thread breaks? ....

What force is acting on the bottom thread? ....

What two forces are acting on the top thread? ....

b) Suspend the weight again as in part (a). Now give a quick jerk downward on the bottom thread. Which thread breaks? .... Using the law of inertia, explain why the threads break as they do in this demonstration. ....

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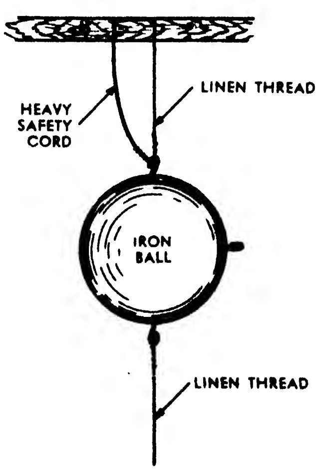

FIG. 230. INERTIA.

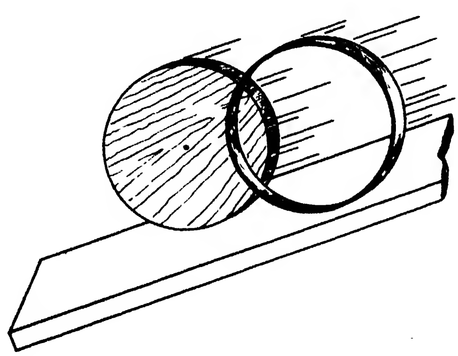
FIG. 231. HOOP AND RING.

c) Suspend the weight as in part (a), attaching a thread to the side of the weight. With this thread, slowly set the weight swinging as a pendulum. Now bring it to a stop by gradually opposing the weight. Why does the thread not break? ....

With the weight at rest, jerk the thread quickly to one side. Why does the thread break? ....

Tie a new thread on the weight and set the weight gradually swinging through an arc of three feet. Now suddenly hold tightly to the thread and let the swinging weight take up the slack. What happens? .... Using Newton's first law of motion, explain why the thread broke in both of the trials ....

....

....

ROTARY INERTIA

In linear inertia, the opposition of a body to being started and stopped depends on its mass alone. In rotary inertia, this opposition is determined by the mass of the body and the distance of this mass from the center of rotation. It is known that the inertia of a rotating body is greater when the mass of the body is concentrated as far from the center of rotation as possible. The moment of inertia is proportional to the product of the mass and to the square of the distance of the mass from the axis of rotation.

$$I = mr^2$$

where I = moment of inertia
m = mass
r = distance radius from center of rotation to the point where the mass is concentrated.

Flywheels are constructed so that most of the weight is concentrated in the rim of the wheel and as far from the center of rotation as is practical. For example, a flywheel weighing 500 lbs. has a radius of 2 feet (to the center of the rim). The moment of inertia is

$$I = mr^2 = 500 \text{ lbs.} \times (2 \text{ ft.})^2 = 2000 \text{ lb.ft.}$$

Demonstration:

Prepare a metal hoop from a section of a large pipe or steel casing. Also turn a block of wood to the same diameter as the metal hoop, cutting its thickness so that it will weigh the same as the steel ring. See Fig. 231.

Place the hoop of metal and the wooden disk side by side on an inclined plane. Release them at the same time. Which one reaches the bottom of the plane first? .... Why?..............................

....

The moment of inertia may be calculated from the formula, $I = mr^2$. The weight of each may be taken as (m). For the wooden roller, (r) is equal to one half the radius of the roller; for the steel rim, the distance

from the center to the midsection of the rim is used for (r). Calculate the rotary inertia of each.

Inertia for the steel rim = ...

Inertia for the wooden disk = ...

From these calculations of inertia moments, explain the action of the two

rollers ....

....

MOMENTUM

The momentum of a moving body is equal to that force which will bring the body to rest in one second by resisting its movement. From this it will be seen that momentum is dependent upon both mass and velocity.

Momentum = Mass × velocity

A light body moving at a high rate of speed has the same momentum and can do the same amount of work as a heavy body moving at a much lower velocity.

Momentum is measured in foot pounds per second (F.P.S.) or centimeter grams per second (C.G.S.) units.

(Note — F.P.S. units are poundals and C. G. S. units are ergs).

These are absolute units and can be converted into gravitational units (pounds or grams) by dividing by (g).

Demonstration:

a) Suspend two balls of hard wood or metal of equal size and weight (Fig. 232) so that contact is made between them. Draw one ball aside a few inches and let is swing so that it will strike the second one squarely. Note the action of the two balls. What

happens to the first ball? ....

....

How does the second ball act? ....

....

The momentum of the first ball is equal to its weight times its velocity at the instant of its impact with the second ball. How is this shown by

the action of the second ball? ....

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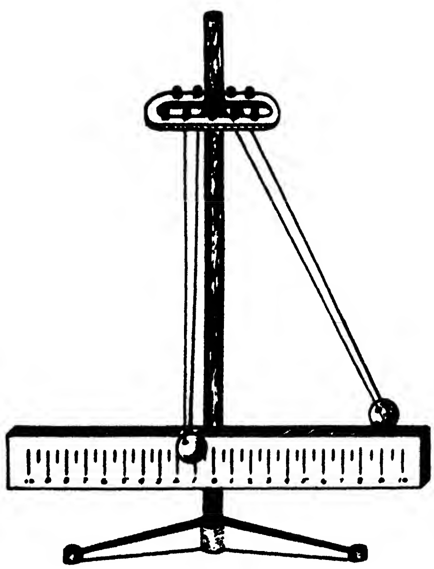

FIG. 232. MOMENTUM APPARATUS.

b) Suspend two balls of different weight, with their centers at the same height above the table. Draw the heavier ball to one side and allow it to

swing against the smaller one. Compare the distances of the swing of each with the masses of the ball. ....

Explain the behavior of the balls using the law of momentum. ....

....

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Repeat the experiment, allowing the lighter ball to fall against the heavier one. Result ....

A large foundry uses the wheel breaking machine, Fig. 233, for crush-

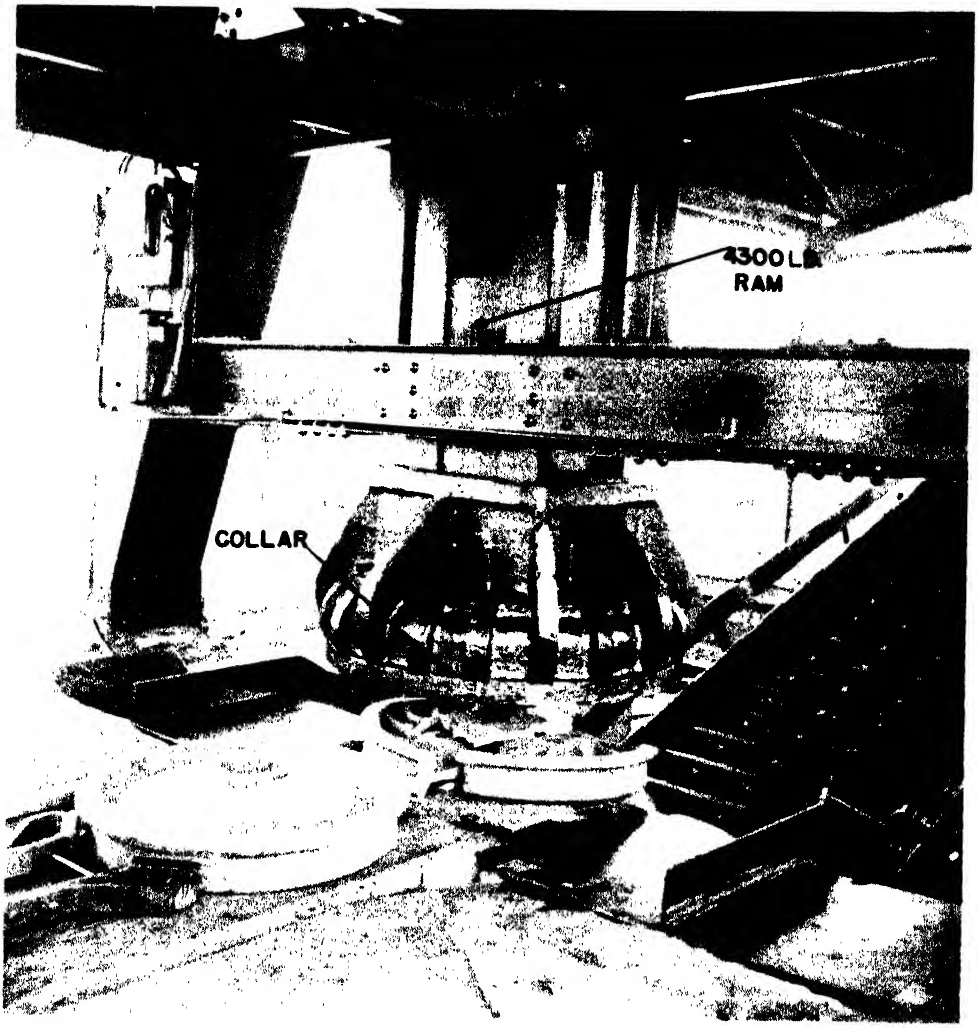

FIG. 233. WHEEL CRUSHING MACHINE. (Courtesy, American Car and Foundry Co.)

ing old freight car wheels into pieces small enough to be charged into the cupola. In use, a wheel is slid into place under the ram by a mechanical pusher, the collar is lowered to hold the wheel in its proper place and to prevent fragments of the broken wheel from flying. A 4300 pound ram

is dropped a distance of four feet, the force of the impact breaking the wheel.

Problems:

Calculate the momentum (F.P.S.) of the 4300 pound ram at the instant it strikes, having dropped a distance of 4 feet. Use the formula:

$$M = mv \text{ where } v = \sqrt{2\ gs}$$

Calculate the K. E. (in foot poundals) of the ram at the instant it strikes. Use the formula: K.E. $= \frac{1}{2}\ mv^2$.

ACCELERATION

The *second law of motion* states that the acceleration of a body is proportional to the force causing it. In other words, if two or more forces act upon a body at the same time, each produces exactly the same effect as if it acted alone.

Demonstration:

With an apparatus similar to that shown in Fig. 234 drop one ball

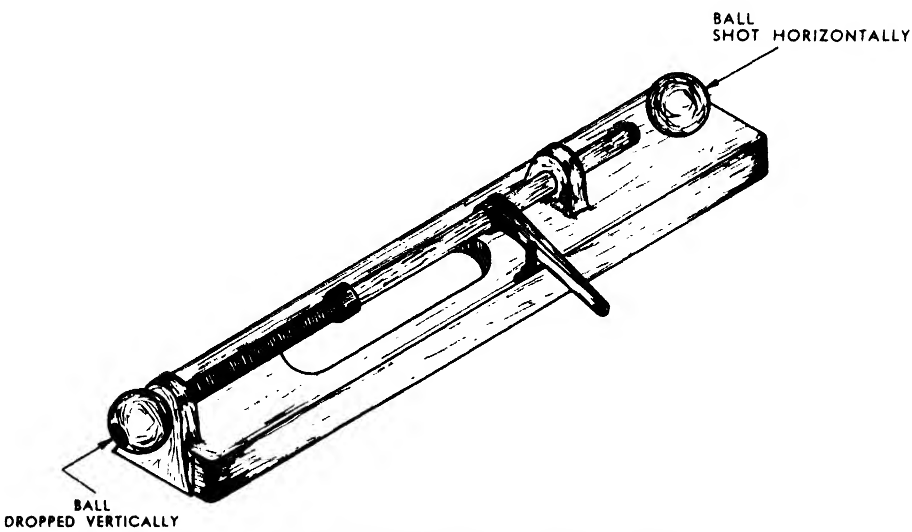

FIG. 234. NEWTON'S SECOND LAW OF MOTION.

bearing vertically and shoot another one horizontally at the same instant.

A body, free to move and being acted upon by a force, will be accelerated as long as the force is acting. Neglecting friction, the force acting on a body may be calculated by the formula:

$$F = \frac{Wa}{g} \qquad \text{(pounds or kilograms)}$$

where (F) is the force, (W) the weight of the body, (a) acceleration in feet per second per second, and (g) the acceleration of gravity. A power-

ful engine in an automobile or an airplane is necessary in order to get the machine up to an operating velocity in a minimum of time.

Example:

What force is needed to accelerate a 3000 pound automobile from rest to 30 miles per hour in 5 sec. (acceleration of 8.8 feet per sec.^{2}).

$$F = \frac{W\,a}{g}$$

$$= \frac{3000 \times 8.8}{32}$$

$$= 825 \text{ pounds}$$

IMPULSE

Impulse is a gain of momentum. A force acting on a body for a long time, accomplishes more than when operating for only a short time. Impulse is the product of a force and the time it acts. Multiply the preceding force formula by (t) time and the result is $Ft = \frac{W\,a\,t}{g}$

From a previous lesson it will be recalled that $v = at$, therefore by substitution $\qquad Ft \text{ (impulse)} = \frac{Wv}{g}$

Powder burning in a gun furnishes the impelling force on the shell. The length of the gun barrel determines the length of time the force acts on the shell. The velocity given to the shell depends upon the time the force acts and the weight of the shell. The momentum of the shell at the time of impact is the product of its weight and velocity. Because of its momentum and kinetic energy, the shell has the ability to do work (the piercing of armor plate, for example). The amount of work that can be done is found by the formula:

$$K.E. = \frac{Wv^2}{2g} \quad \text{(foot pounds)}$$

TRAJECTORIES

The path that a bullet or a bomb takes in the air is in accord with the laws of motion. Its path is the resultant of two forces acting on the body; one, the force of gravity, and the second, the impelling force behind the body. If it were not for gravity, a shell would continue in a straight line until air resistance dissipated its energy. Gravity, however, is constantly acting on a moving body so that its path through the air is a parabola.

Demonstration:

The trajectory of a shell may be effectively demonstrated by using a small stream of water under pressure, from a hose. Hold the hose horizontally and study the flat trajectory of the water. Make a sketch of the flat trajectory made by the stream of water.

Hold the hose at an angle of about 30° with the horizontal. Observe the trajectory. Repeat at 45° and 60°. Sketch the water trajectories at these angles, all starting from the same point.

If an object is to be thrown at a target some distance away, it must be made to arc through the air in order to hit the target. When firing a rifle at a distant target, the sight is raised. The reason for this has been demonstrated by projecting a ball bearing horizontally and dropping another of the identical size and weight vertically at the same time. See Fig. 234.

Example:

A rifle bullet has an average velocity of 1000 ft. per sec. If the rifle is held horizontally 5 feet above the ground, the bullet will strike the ground in .56 of a second. (Fig. 235A.)

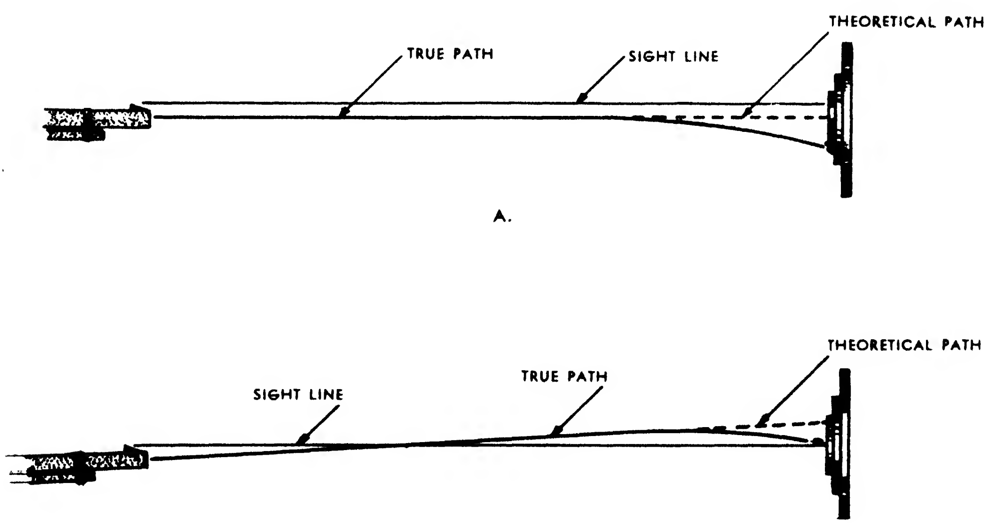

FIG. 235. PATH OF A RIFLE BULLET.

Solution:

$$s = \tfrac{1}{2}\, gt^2$$
$$5 \text{ ft.} = \tfrac{1}{2} \times 32 \times t^2$$
$$5 = 16\, t^2$$
$$t^2 = .3125$$
$$t = .56 \text{ seconds}$$

The rifle bullet, in .56 of a second, will have traveled 560 feet.

$$s = vt$$
$$s = 1000 \text{ ft/sec} \times .56 \text{ sec.}$$
$$s = 560 \text{ ft.}$$

In order to hit a target a given distance away, it is necessary to know the average velocity of the bullet for various distances. The aim must be as great a distance above the object as the bullet will drop in the time it takes to travel to the target. Fig. 235B shows the adjustment necessary for the example given. The barrels of large cannon must be elevated in order to allow for the falling of the shell due to gravity, wind resistance, air friction, etc., to lay a barrage to protect advancing infantry and tanks. The trajectory of a bomb being dropped from an airplane is illustrated in Fig. 236.

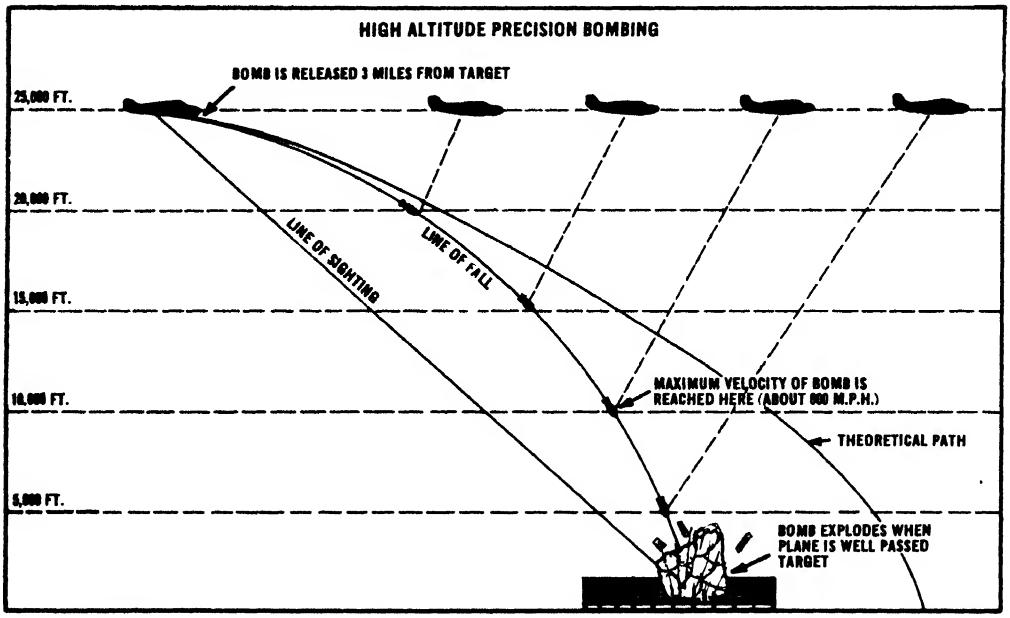

FIG. 236. HIGH ALTITUDE PRECISION BOMBING.

Summary:

A trajectory is the path of a .... through the air, and theoretically is the resultant of a .... and a .... force. In addition to these two forces, ...shortens the path of a body through air. The vertical component is the force of........... .... which pulls it downward with an acceleration of .... ft./sec.^{2}. A stream of water flowing from a hose shows that the first part of the trajectory is fairly flat because the horizontal .... is great while the vertical .... is small. The shape of the curve near the end of the stream is rounded, because the horizontal ....

is ...., and the vertical .... is ....

Tracer bullets are used for the purpose of ....

The instrument used for finding the distance to a target is called a ....

.... The instrument for aiming a bomb is a ....

Problems:

A 75 mm. field gun shell has an average velocity of 2000 feet per second. If it is fired at a target 5 miles away (a) how long will it take the shell to travel to the target? (b) How far above the target must the gun be aimed? (c) At what angle will the gun need to be elevated? (Suggestion: use right triangle geometry) Neglect air resistance.

NEWTON'S THIRD LAW

The *third law of motion* states that for every action (force) there is an opposite and equal reaction (force). When a gun is fired, the bullet is driven out in one direction, the gun recoils (kicks) in the opposite direction. The tires of an automobile grip the road and push the car forward. The road pushes pack on the tires. When the road is icy, the tires do not push due to lack of friction and the wheels spin uselessly.

To demonstrate the third law, hook two spring balances together and exert a pull on one of them. Read both scales. Are the readings alike? Hang a known weight vertically on a spring balance. Is the balance pulling upward with the same force that the weight is pulling downward?

Conclusions ....

....

How do the oars of a row boat, the propeller of an airplane, the track of a tank, illustrate Newton's third law of motion? ....

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CURVILINEAR MOTION

CENTRIFUGAL FORCE

When a body is moving in a circular path, there are two forces acting on the body. One force is producing motion forward and the second is exerting a force toward the center of the circle, keeping the body in a curved path. A stone whirled about one's head on a string, exerts a pull on the string. The string pulls back on the stone. If the string were to

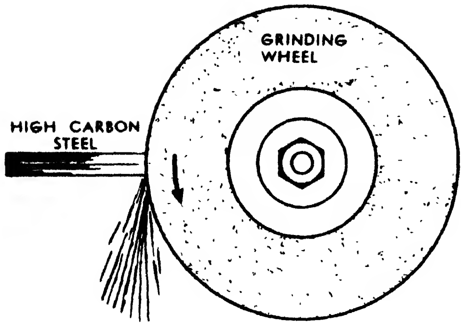

FIG. 237. CENTIFRUGAL FORCE.

break, the stone would fly outward in an almost straight line. This is illustrated by sparks leaving a rapidly turning emery wheel, Fig. 237. The tendency for a body to fly off into space is called "centrifugal force"; the force preventing it from flying off is called "centripetal" force.

The formula for centrifugal force is derived from Newton's second law of motion.

$$F = \frac{W\,a}{g} \qquad (1)$$

The acceleration, for uniform circular motion, is equal to the velocity squared divided by the radius of rotation.

$$a = \frac{v^2}{r} \qquad (2)$$

Therefore

$$F = \frac{W\,a}{g} = \frac{W\,v^2}{gr} \qquad (3)$$

Now velocity of a body in circular motion is equal to the number of revolutions per second times the circumference —

$$v = 2\pi r\,N \qquad (4)$$

therefore

$$v^2 = 4\pi^2 r^2 N^2 \qquad (5)$$

Substituting (5) in formula (3)

$$F \text{ (centrifugal force)} = \frac{Wv^2}{g\,r} = \frac{W\,4\pi^2\,r\,N^2}{g}$$

Example:

The counter balance weight on a crank shaft weighs 2 lbs. The radius of its rotation is .5 feet. If the engine is revolving at 1800 revolutions per minute what is the centrifugal force of the counter balance?

Solution:

$$\frac{1800 \text{ R.P.M.}}{60} = 30 \text{ revolutions per second}$$

$$F = \frac{W\,4\pi^2\,r\,N^2}{g}$$

$$= \frac{2 \times 4 \times (3.14)^2 \times .5 \times 30^2}{32}$$

$$= \frac{2 \times 4 \times 9.86 \times .5 \times 900}{32}$$

$$= 1109.25 \text{ lbs.}$$

The applications of centrifugal force are many. Machines utilize the centrifugal force of a rotating body to do useful work. For example, cream is separated from milk by rotating a stream of the liquid in a centrifuge (cream separator). Sugar crystals are separated from molasses with a

centrifugal filter. Many washing machines dry clothes by spinning the wet clothes in a perforated drum. Oil may be dewaxed by centrifugal force. The speed of machinery is controlled by governors (rotating weights) opening and closing valves by centrifugal action. Water and other fluids may be pumped by a centrifugal pump. Fig. 238A is an open view of a three stage

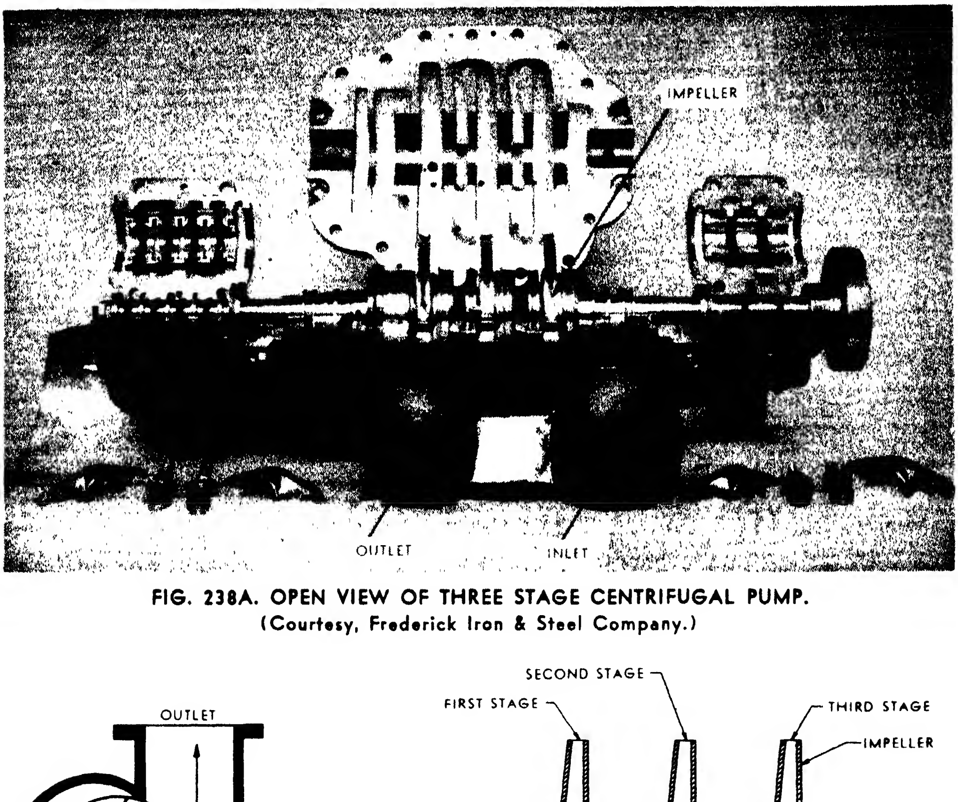

FIG. 238A. OPEN VIEW OF THREE STAGE CENTRIFUGAL PUMP.
(Courtesy, Frederick Iron & Steel Company.)

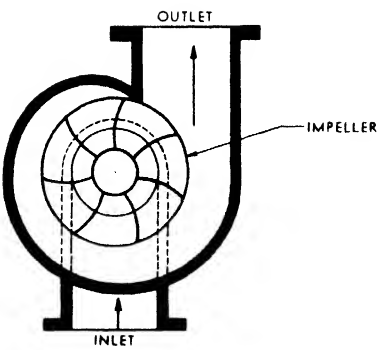

FIG. 238B.

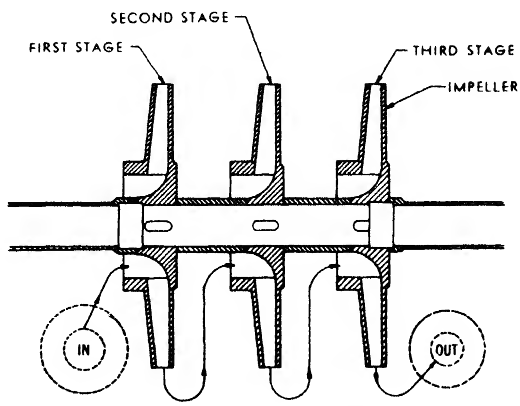

FIG. 238C.

centrifugal pump. The impeller, Fig. 238B, has blades which are usually curved backward in relation to the direction of rotation. The liquid enters near the hub of the impeller, is caught between the whirling blades and hurled outward by centrifugal force into the delivery space around the impeller, passing out through the discharge opening. In order to develop higher pressures than a single stage centrifugal pump can supply, from two to six stages are built into a single housing. In a three stage pump the liquid enters the suction of the pump, Fig. 238C, is picked up by the im-

peller of the first stage and discharged by the pressure of the impeller into a volute chamber. It then flows through a connecting chamber or passageway to the suction of the next stage, each stage boosting the pressure of the previous stage until the fluid leaves the final discharge outlet.

Even amusements make use of centrifugal force, the carnival "whip," the "flying swings," the rotating platform, are examples. Centrifugal force is also the cause of accidents, such as the overturning of an automobile or a train rounding a curve at too high a speed. In order that such centrifugal forces may be neutralized, highways and railroad beds are banked on curves. (See Fig. 239.) The angle of banking is determined by the expected centrifugal force.

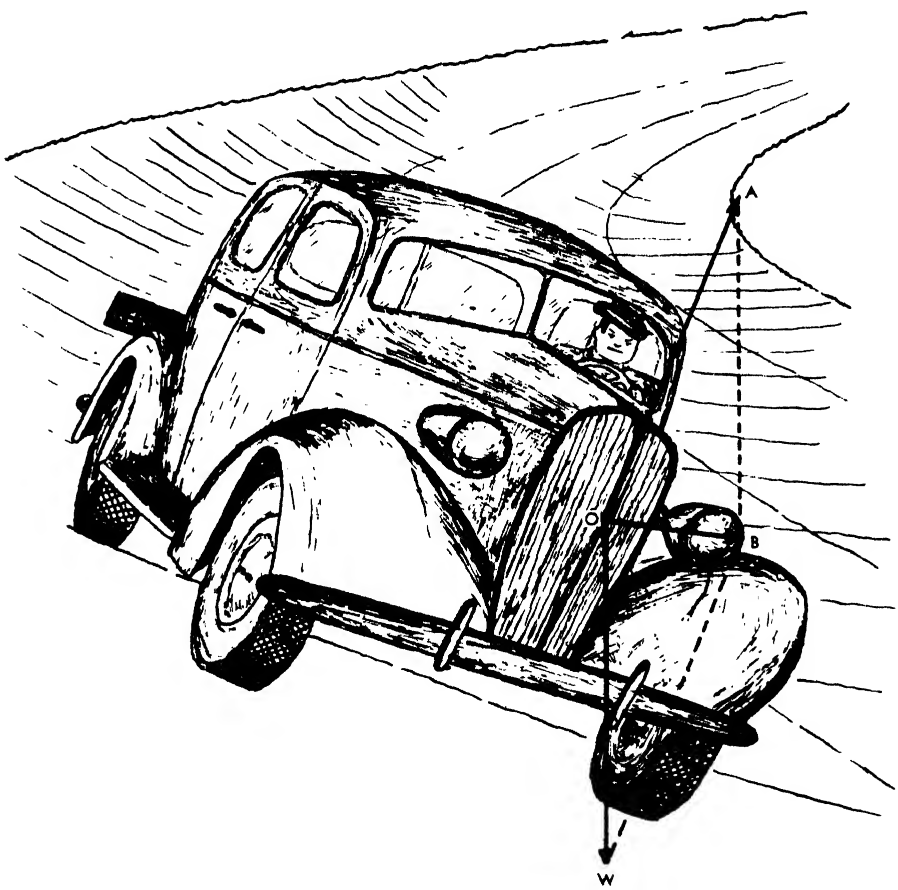

FIG. 239. BANKED HIGHWAY.

CENTRIFUGAL CLUTCH

The centrifugal clutch is an automatic clutch. Internal clutch shoes, similar to brake shoes, push against the inside of the clutch drum when the centrifugal force of two governor weights becomes great enough. At motor speeds above 400 r.p.m., the centrifugal force begins to press the

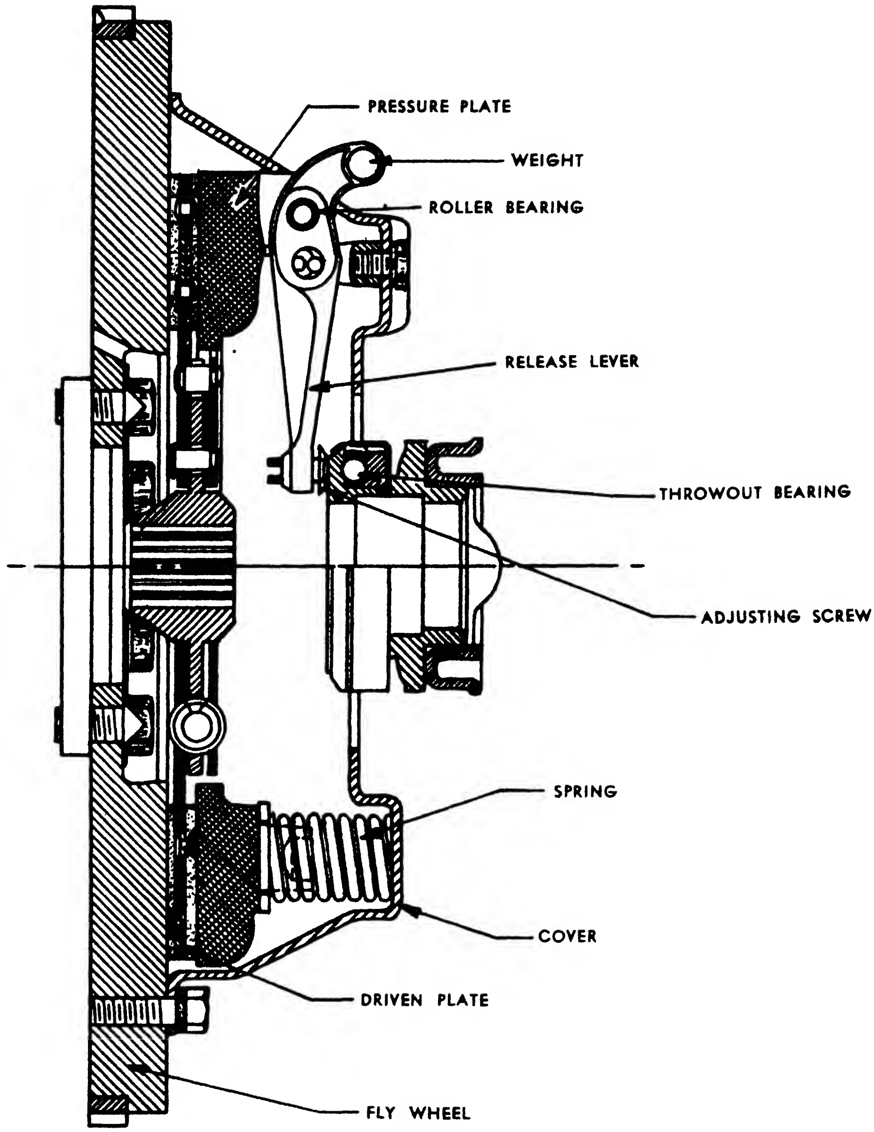

FIG. 240. SEMI-CENTRIFUGAL CLUTCH.

clutch shoes against the clutch drum, and full pressure occurs at 800 r.p.m. This type of clutch is used with automatic transmissions.

The semi-centrifugal clutch, Fig. 240, has three curved spring levers, weighted at the end. These weights fly outward as the speed of rotation increases. The centrifugal levers are so arranged that they aid in holding the clutch plates tightly together instead of using a constant spring pressure, thereby reducing the amount of pedal pressure necessary to disengage the clutch.

CENTRIFUGAL SPARK ADVANCE

Centrifugal force is used to advance the spark in the distributor assembly. (See Fig. 241.) As the distributor rotates, the centrifugal weight levers are thrown outward. The opposite ends of the weight levers turn

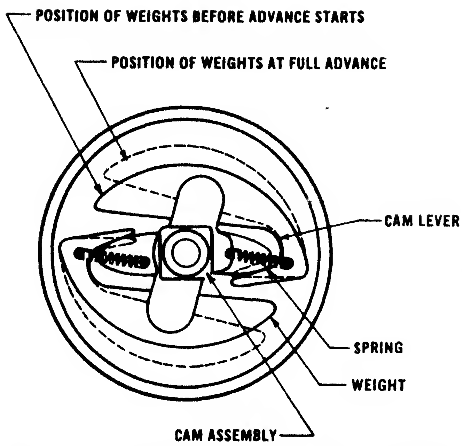

FIG. 241. CENTRIFUGAL SPARK CONTROL.

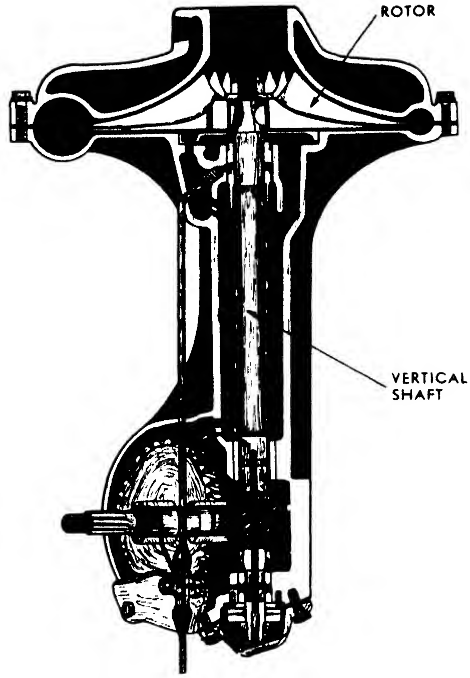

FIG. 242. SUPERCHARGER.

the breaker forward, thereby causing the spark to advance as the engine speed increases. Springs readjust the position of the levers as the engine speed slows down.

TURBO - SUPERCHARGERS

The turbo-supercharger is, in reality, a centrifugal pump, (See Fig. 242) turned by the engine crank shaft or impelled by the exhaust engine gas. The air scoop forces air into the center (a) of the rapidly turning vanes of the supercharger. By centrifugal force the air and gas mixture are thrown outward at high speed toward the cylinder ports. In the cylinder manifold, the speed is reduced, thus increasing the pressure of the gas on the intake port. Superchargers are used on high speed engines or on airplane engines which operate in the substratosphere in order to furnish sufficient oxygen to burn the fuel in the cylinders at low air pressure. The turbosupercharger is a triumph of modern metallurgy, one end of the rotating element operating at a temperature of $-67°F$ while the impeller blades, only a few inches away, may be heated as high as $1500°F$. The impeller blades rotate at speeds in excess of 20,000 r.p.m., a speed at which most metals would fly apart.

CENTRIFUGAL AIR CLEANER

The centrifugal air cleaner, Fig. 243, is a round sheet metal container having the air entrance vaned so that the air is whirled around the inner circumference before it enters the carbureter. Centrifugal force throws the heavier dust particles outward through a small slit in the body of the cleaner. Centrifugal cleaners are used most often with up-draft carburetors. They are often used as "pre-cleaners," being installed ahead of oil

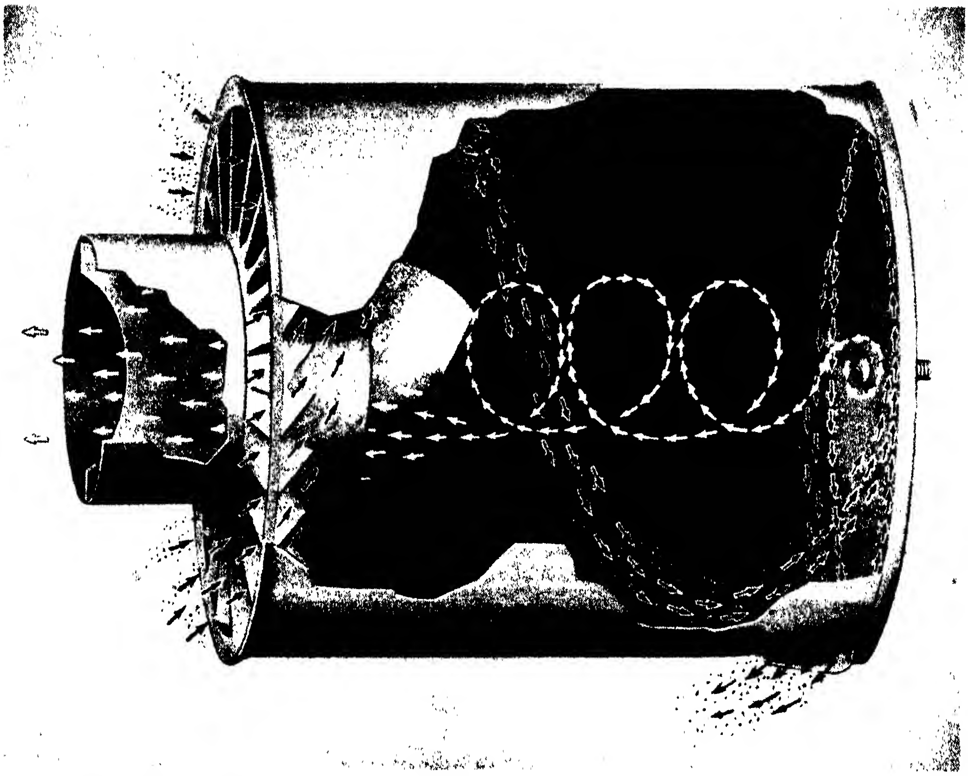

FIG. 243. CENTRIFUGAL AIR CLEANER. (Courtesy, A. C. Spark Plug Division, General Motors Corporation.)

bath cleaners on vehicles which may be used in desert service.

New Words:

ANGULAR VELOCITY.—The velocity of a body moving in a curved path, the acceleration being toward the center of the curve.

CENTRIFUGAL.—That force which tends to cause a body, moving in a curved path, to fly off at a tangent to the curve.

CENTRIPETAL.—That force exerted on a body, which tends to hold it on a curved path by exerting a pull toward the center of curvature.

CUPOLA.—A tall, stack-like furnace, for remelting cast iron.

CURVILINEAR.—The path of a body moving in a curved line.

ERG.—A unit of work. The work done by one dyne of force acting through a distance of one centimeter.

IMPELLED.—To drive or to push forward.

IMPULSE.—A force acting for a given length of time.

MOMENTUM.—Quantity of motion. Equal to the mass of body times its linear velocity.

PARABOLA.—A word used to describe a type of geometric curve.

POUNDAL.—An absolute unit of force. The force required to give a mass of one pound an acceleration of one foot per second per second.

PROJECTILE.—A body, projected or thrown through space, as a ball or a bullet.

RARE ATMOSPHERE.—The atmosphere at high altitudes under low pressure — the stratosphere.

ROTARY.—Moving in a circle or about a fixed axis.

TRACER BULLET.—A bullet treated to produce a trail of smoke or a path of phosphorescent light.

TRAJECTORY.—The geometric path of a body projected through the air.

SUPERCHARGER.—A machine used to increase the volume and pressure of a mixture of gas and air before entering the cylinders of a gas engine.

VOLUTE.—A spiral shaped passage.

Additional New Words:

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MACHINES USE HEAT ENERGY

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Fletcher: *Unified Physics*, pages 195-203.
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Millikan: *New Elementary Physics*, pages 188; 207-215.
Johns-Manville: *Heat*.

SOURCES OF HEAT

The sun was worshipped by ancient people as a god. The sun, to them, was a source of light, heat, and protection; its presence was forever welcome. Today, we also realize the necessity of the sun's light and heat, which reaches the earth by radiation. It is also believed that the ultimate source of all heat upon the earth is the sun. If the sun's heat energy were shut off from the earth for one day, a vast pall of cold and darkness would envelop the earth. The oceans would become covered with a thick sheet of ice, vegetation would be blighted and all life slowly but surely blotted out.

It is believed that ancient plants, whose growth was stimulated by the absorption of heat energy, gave rise to beds of coal, deposits of oil and gas in the earth. When these substances are burned, the original heat absorbed from the sun's rays is liberated and can be utilized by machines.

Substances that possess the ability to release heat may be utilized as fuels. Most of our fuels are chemical substances that release their heat energy when the proper conditions of chemical change have been provided. These conditions are those of temperature, pressure, catalytic action and the presence of other active substances. Chemical reaction between two or more substances results in an exchange of heat. If heat is given off the action is classified as exothermic; if heat is taken in, the reaction is endothermic.

Mechanical action generates heat. Much of the mechanical energy of a machine is lost in the form of heat. When substances are hammered, twisted, bent or otherwise deformed, heat is always generated. The rubbing of two bodies together will generate heat. This type of heat is the result of friction.

Heat may also be generated by the compression of a gas. When the volume of a gas is decreased by pressure, the temperature rises proportionally. This principle is utilized in firing the fuel in a diesel engine.

The entrapped air is reduced to one sixteenth of its volume by the pressure of the piston. Forced into such a small space, the temperature rises to such a degree that the fuel sprayed into the cylinder is burned instantly. The burning fuel releases more heat energy, which in turn causes the pressure to rise rapidly, thereby pushing the piston downward.

The passage of an electric current through a conductor is always accompanied by the evolution of heat. The amount of heat given off, is proportional to the resistance of the conductor and to the amount of current flowing through it. In general, good conductors of electricity are also good conductors of heat. Heating appliances such as irons, toasters, etc. depend upon the fact that the passage of current over a conductor causes heat to be generated, a fact that accounts for most of the losses and reduced efficiency in electrical machinery.

SOURCES OF HEAT

Purpose:

To study various methods of producing heat.

Tools and Materials:

Radiometer
Concentrated sulphuric acid
Quicklime
Ammonium chloride
Thermometer
#22 nichrome wire
Steel wire
Sheet lead or copper
Fire syringe
Tyndalls friction cylinder
Storage battery
Rheostat

Procedure:

a) Radiant energy

Set up the radiometer, Fig. 244, so that sunlight falls upon its vanes. In what direction does it turn? ....

Refer to a physics text book on the radiometer and explain why it turns. ....

....

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....

To prove that it is heat and not light that affects the radiometer, set the radiometer away from the window and bring the end of a bar

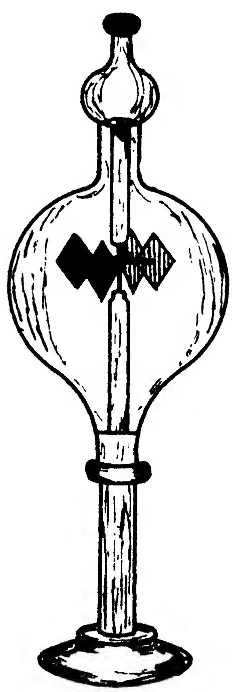

FIG. 244. RADIOMETER

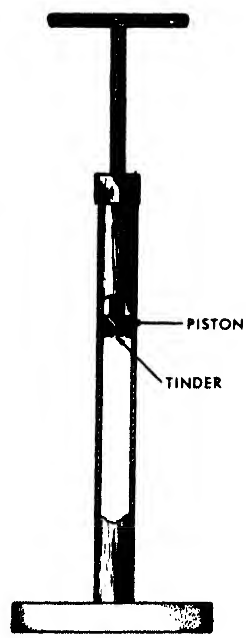

FIG. 245. FIRE SYRINGE.

of metal that has been heated in a bunsen flame near it. This shows that (heat, light) .... causes the radiometer to rotate.

b) Chemical energy

1) When chemical reactions take place, noticeable heat is usually given off. Pour slowly (caution) some concentrated sulfuric acid into a test tube half filled with water. (Caution: always pour an acid into water — never the reverse.)

Feel the test tube with the hand. Is there evidence of heat being generated? ....
This heat is produced by the action of sulphuric acid and water in forming a hydrate of sulfuric acid.

2) Into a test tube half full of water, drop a small lump of calcium oxide (quicklime). Is there evidence that heat is produced? ....
The resulting solution is calcium hydoxide (slaked lime or lime water).

c) Heat of solution

To a test tube half full of water, add a teaspoonful of ammonium chloride. Close the mouth of the test tube and shake. Now feel the test tube with the hand. What evidence is there of absorption of heat? ....

....

d) Heat from mechanical energy

1) Bend a piece of stiff wire back and forth rapidly until it breaks. Hold the portion that breaks against the bulb of a thermometer. Does the thermometer show that heat is produced? ....

2) Pound a lump of lead or copper with a hammer for a few minutes. Now touch the metal to the bulb of a thermometer. Is there evidence that heat is produced? ....

3) The fire syringe, Fig. 245, demonstrates in a striking manner the conversion of molecular, kinetic energy, into heat. To use, some dry tinder is placed in the cup at the bottom of the piston. The piston is started gradually into the cylinder and then suddenly and vigorously forced down as far as it will go. When quickly withdrawn, the tinder will be found burning, heat having developed due to the compression of the air in the cylinder.

If a fire syringe is available, place a piece of charred linen on the end of the piston. Insert the piston in the cylinder and force it downward quickly. Withdraw the piston. Is there evidence that compression will liberate heat from a gas? ....

4) Allow air to escape from a compressed air tank (or auto tire) that has been under pressure for some time. Hold a thermometer in the air stream. Is there evidence that heat is absorbed by the escaping gas? ....

....

Was the compressed air in the container above or below this temperature?

....

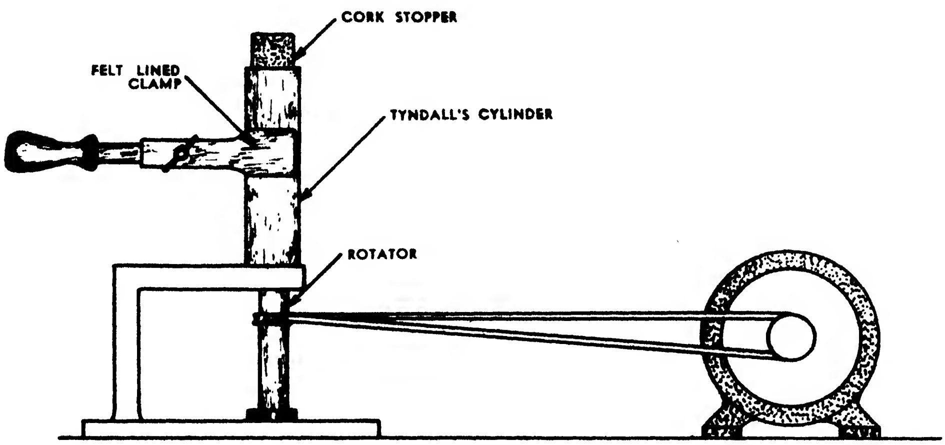

FIG. 246. FRICTION CYLINDER.

5) **Tyndall's friction cylinder, Fig. 246, consists of a brass tube mounted on a rotating unit. A hand friction clamp of wood or metal lined with felt, is placed around the cylinder and the cylinder filled with water or alcohol. The liquid is made to boil by means of frictional heat developed by rapidly rotating the cylinder between the jaws of the clamp. A closely fitted stopper inserted in the end of the tube is violently expelled by the vapor pressure of the boiling liquid.**

If the apparatus is available, try this experiment.

e) Heat from electricity

Connect a six volt storage battery, a heavy duty rheostat, and one foot of #22 nichrome wire in series. (A six volt light bulb may be used in place of the wire). Turn on the current slowly while holding to the nichrome wire with the fingers. Increase the current until the wire feels warm, then again increase the amount of current flowing through the wire. Is there evidence that increased current gives an increased amount of heat?

....

This heat effect may also be demonstrated by taking the temperature near the bulbs of 25, 40, 75, and 100 watt light bulbs. How does a fuse safeguard an electric circuit against large amounts of heat? ....

....

Questions:

1. **All heat upon the earth originally came from the** ....

   The heat from the sun reaches the earth by ....

2. **Heat is produced by three methods, namely,**......................................

   ...., **and** ....

3. When chemical reactions take place, heat is either .... or .... A chemical reaction in which heat is given off is called a(n) .... reaction; when heat is absorbed it is a(n) .... reaction.
4. Substances that oxidize rapidly, giving off great quantities of heat, are called .... Some of the most common of these .... are ...., ... and ....
5. Gasoline and Diesel engines are heat engines because they depend upon heat for their operation. Explain how each uses heat energy in its operation. ....
....
....
6. Heat may be produced mechanically by deforming a substance. Three kinds of mechanical deformations are 1) .... 2) .... and 3) ....
7. Mechanical efficiency is never 100% due to .... being formed. The type of heat usually generated by mechanical action is called heat of ....
8. When a current of electricity passes through a wire .... is generated. The amount of .... generated is proportional to the .... and .... Three common household appliances dependent upon these facts are the ...., ... and ....
9. Electric motors and generators are never 100% efficient due to........ .... losses.

New Words:

CATALYTIC.—The action caused by a catalyst. A catalyst causes a chemical reaction to occur but remains unchanged itself.

ENDOTHERMIC.—A chemical reaction which absorbs heat.

EXOTHERMIC.—A chemical reaction which produces heat.

FUSE.—A metal composed of zinc or lead which melts at a low temperature; used to protect an electrical circuit.

OXIDIZE.—The process of combining chemically with oxygen.

RADIOMETER.—An instrument for measuring and detecting small amount of radiant (heat) energy.

TINDER.—Any dry, easily inflammable, substance.

VANE.—A flat, fan shaped arm, projecting from an axis.

VOID.—Empty, vacant, unoccupied, lifeless.

Additional New Words:

....

....

....

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....

....

HEAT PRODUCES EXPANSION

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 232-251.
Dull: *Modern Physics*, pages 205-232.
Fletcher: *Unified Physics*, pages 195-210.
Millikan: *New Elementary Physics*, pages 188-204.

Introduction:

Heat is a form of energy, being caused by the motion of atoms and

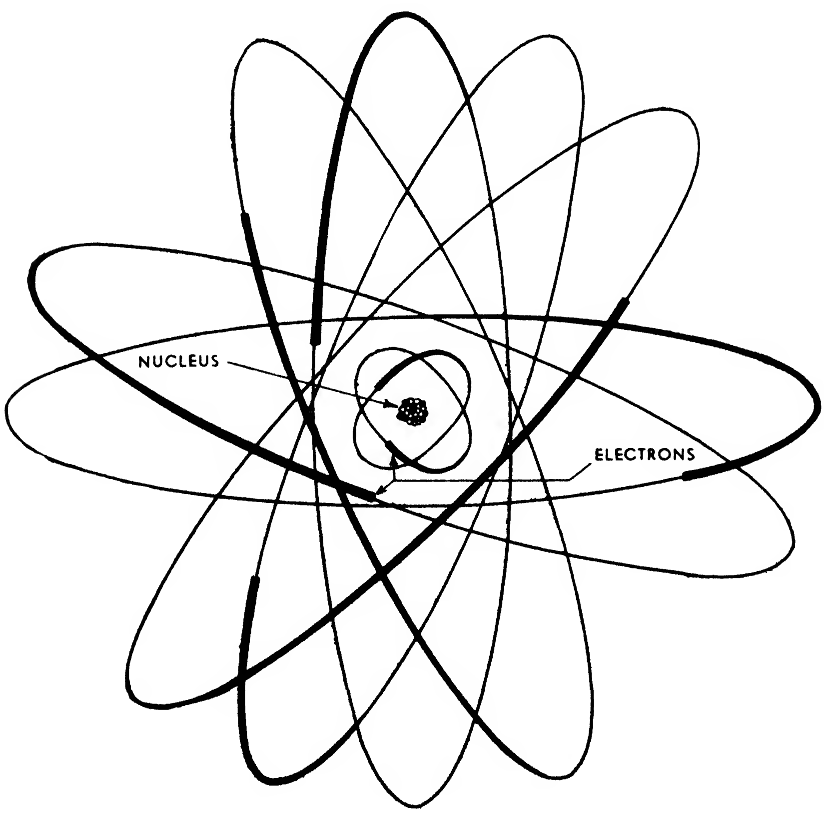

FIG. 247. OXYGEN ATOM.

molecules which make up materials. The intensity of heat energy is known as temperature. From this it is seen that heat and temperature are not the same, a fact which will become more evident as study of the subject is continued. Solids, liquids and gases expand when heated and contract when cooled.

CAUSE OF EXPANSION

Atoms are composed of electrons (negative particles of electricity) and protons (positive particles of electricity) arranged in a manner similar to our own solar system. Illustrated in Fig. 247 is the modern conception of an oxygen atom. The electrons are moving in definite paths (orbits) around a central nucleus. In liquids and solids, heat tends to increase the average atomic volume. Many solids have a definite crystalline structure. In Fig. 248 is shown the cubic space lattice of alpha iron (iron at room temperature). In such solids, heat widens the spacing of the atoms in the lattice. These two facts account for the expansion of solids and liquids when heat is applied. The expansion of gases has been discussed in connection with Charles' Law and the internal combustion engine. The molecules of gases are much farther separated from each other than those of solids and liquids. Gases expand when heated because of the increased kinetic energy of their molecules.

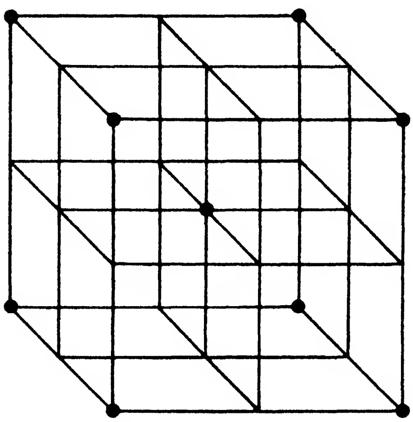

FIG. 248. CUBIC CRYSTAL LATTICE.

MEASUREMENT OF TEMPERATURE

Temperature is commonly measured with a thermometer. Thermometers are made of long glass tubes with a fine and uniform bore. A bulb is blown on one end of the tube, the tube then filled with mercury (or colored alcohol) and heated until the liquid flows over the top of the tube. When this occurs, the open end of the tube is sealed by heating in a hot flame. As the liquid cools, it contracts, leaving a vacuum in the tube above it. From this it is seen that the operation of a thermometer depends upon the expansion and contraction of a liquid when heated or cooled.

There are three types of thermometer scales in common use, the Fahrenheit, Centigrade and Absolute, Fig. 249. The Fahrenheit scale was designed in 1714 by the German physician, Daniel Fahrenheit. He made the 0° on the scale the temperature of a mixture of salt and ice; the boiling point of pure water (at the pressure of the air at sea level) he marked 212°; the freezing point of pure water he marked 32°. It will be noticed that there are 180° between the freezing and boiling points. It is supposed that Fahrenheit arrived at this number by using a half circle (360°) as the basis of his scale.

The Centigrade scale was devised by Anders Celsius, a Swede, and later revised to its present form by Christin, a Frenchman. Freezing point

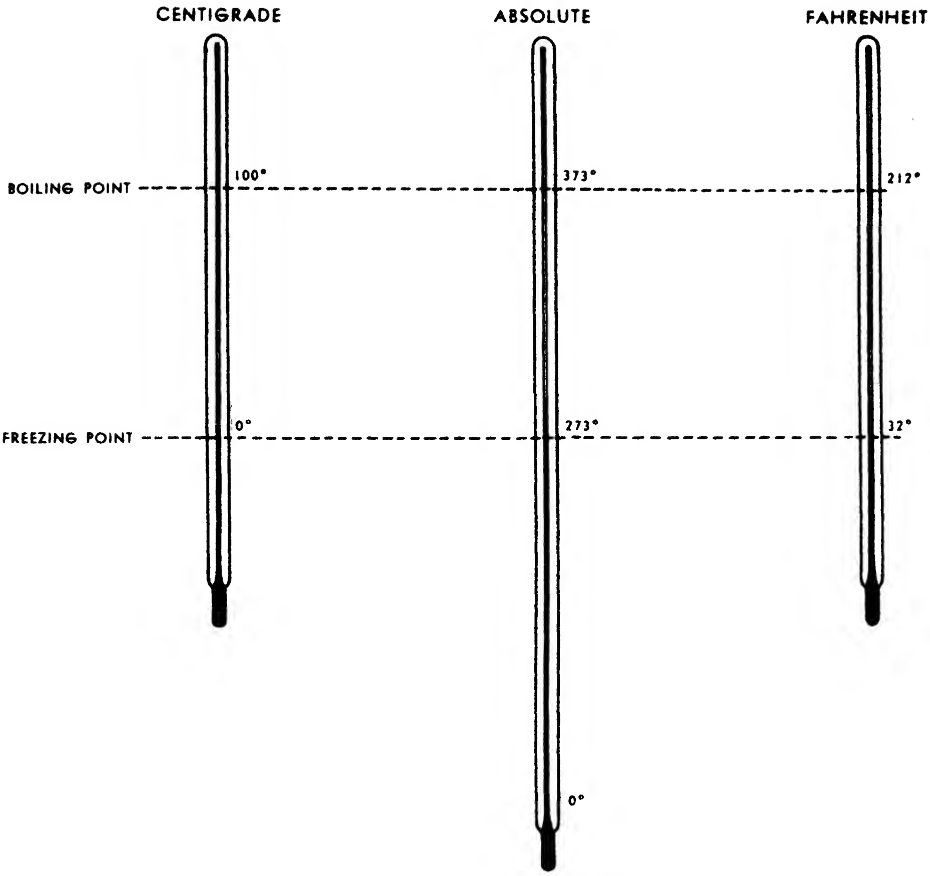

FIG. 249. TEMPERATURE SCALES COMPARED.

of water on this scale is 0° and the boiling point is 100°. Absolute scale is used in connection with Charles' Law.

Since mercury freezes at –38°F and boils at 674°F, it is used in thermometers which record relatively high temperatures. Some mercury thermometers are made to register as high as 1000°F by sealing an inactive gas, such as nitrogen, in the tube above the mercury, thus increasing the pressure on it.

Grain alcohol freezes at –179.1°F and boils at 173.3°F, therefore it is used when lower temperatures are to be measured. It is usually colored red to make reading easier.

MEASURING HEAT

Heat is measured by means of a calorimeter, Fig. 250. The metric unit of heat is the calorie. A small calorie (c) is the amount of heat needed to raise the temperature of 1 g. of water 1°C. A large calorie (C) is 1000 small calories.

The English unit of heat is the British Thermal Unit (B.T.U.). It is the amount of heat needed to raise one pound of water 1°F.

SPECIFIC HEAT

Water is often used as a standard of comparison, not only because of

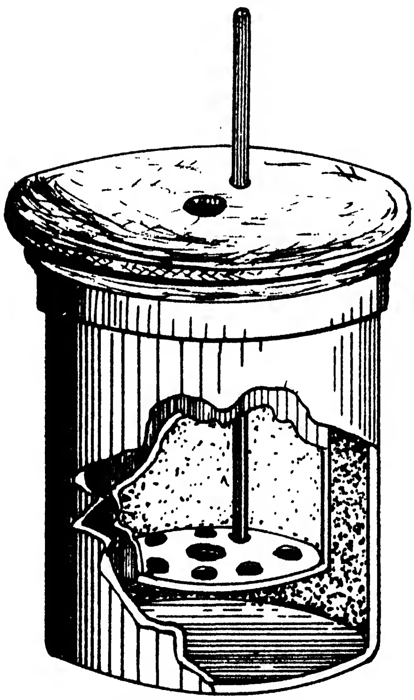

FIG. 250. CALORIMETER.

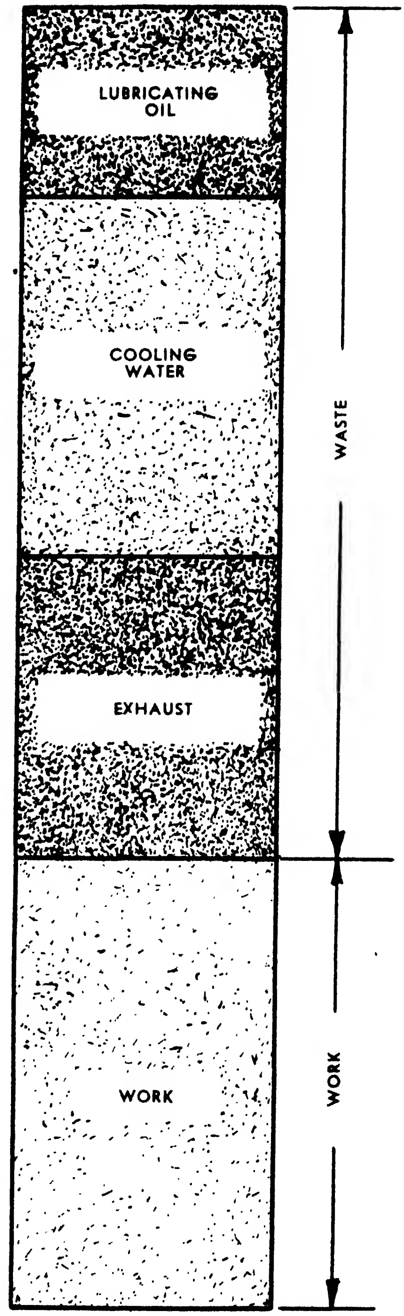

FIG. 251. THERMAL EFFICIENCY OF A DIESEL ENGINE.

its abundance but because it has many special properties. The expansion of water is irregular. When water at 0°C is heated, it contracts until it reaches 4°C; above 4°, heat causes the normal amount of expansion. This behavior of water accounts for the fact that ice freezes on top of a body of water rather than from the bottom.

Water also absorbs more heat (per gram or pound) than any other

substance. Because of this, the amount of heat other substances can absorb (specific heat), is measured in comparison with the heat absorbing capacity of water.

In determining the specific heat of a substance, use is made of the "law of mixtures." According to this law, when substances of different temperatures are mixed (assuming no heat is lost by radiation):

1. The substances will become the same temperature.
2. The total amount of heat before and after mixing will be the same.
3. The total heat lost by the substance of higher temperature will be the same as the total heat gained by the substance of lower temperature.

Some machines, such as the gas refrigerator, use heat exchangers in order to increase their thermal efficiency. The thermal efficiency of a diesel engine is about 35%. Fig. 251 shows that 35% of the heat produced by the cylinders of a diesel engine is efficiently harnessed as work and that 65% is wasted in the exhaust gases, cooling water and lubricating oil.

New Words:

SOLAR SYSTEM.—The sun and the system of planets which revolve around it.

ORBIT.—The circular path in which a planet moves around the sun; or an electron around the nucleus of an atom.

KINETIC ENERGY.—Energy of motion.

BORE.—The inside diameter of a circular hole.

SPECIFIC.—Meaning ratio or comparison.

THERMAL EFFICIENCY.—The amount, in percentage, of heat harnessed for a useful purpose.

Additional New Words:

________________ ....

....

________________ ....

....

________________ ....

....

COEFFICIENT OF EXPANSION

Purpose:

1. To observe the expansion of solids when heated.
2. To measure the coefficient of expansion of various metals.

Tools and Materials:

Brass ball and ring	Brass tube
Thermometer	Aluminum tube
Compound bar	Steam boiler
Micrometer	Meter stick
Linear expansion apparatus	

Procedure:

a) Ball and ring

To show the expansion caused by heat, and contraction due to cooling,

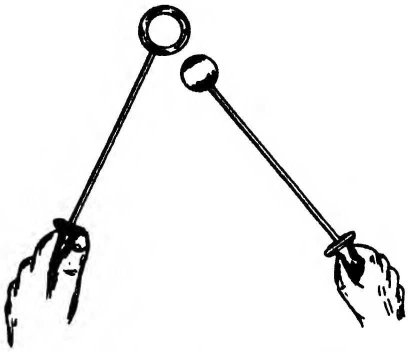

FIG. 252. BALL AND RING.

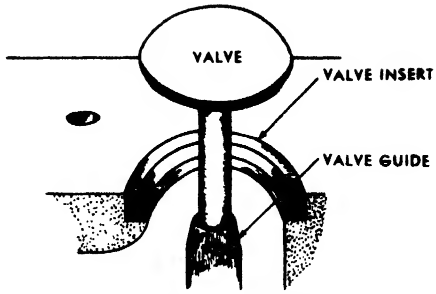

FIG. 253. VALVE INSERT.

use the ball and ring as pictured in Fig. 252. First try passing the ball through the ring when both are at room temperature. Then heat the ball and try to pass it through the cool ring. Several other trials may be made by heating the ring and cooling the ball, etc.

While this is a seemingly simple experiment, the principle it illustrates has several practical applications. The valve inserts, Fig. 253, are placed in a motor block after they have been cooled in liquid air. When the inserts warm up to room temperature they expand and fit tightly in the motor block.

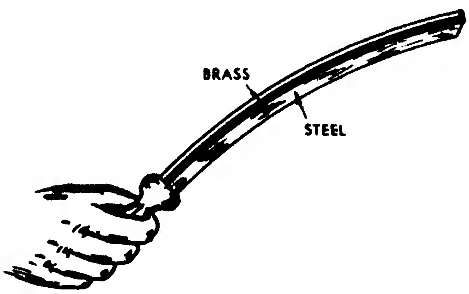

FIG. 254. COMPOUND BAR.

b) The compound bar

The compound bar, Fig. 254, consists of two unlike metals riveted or welded securely together. Since the two metals expand at different rates, the bar will bend in one direction when heated and in the opposite direction when cooled. This principle is also used in the construction of thermostats.

Heat a brass-steel compound bar and observe the direction in which it bends, then cool the bar. Since brass expands (more, less) .... when heated than steel, the bar bends toward the (brass, steel) .... when it is heated.

c) Coefficient of expansion

Set up the apparatus as shown in Fig. 255. Using a brass rod, make the distance between the knife edge support and the pointer spindle exactly 100 cm. Measure the diameter of the spindle accurately with a metric micrometer. Place the pointer on 0°, then pass steam through the tube as long as the pointer continues to move. Read the number of degrees the pointer moves, and take the temperature of the steam in the boiler. Record all measurements in Table LVI and complete the calculations for determining the linear coefficient of expansion.

Repeat the experiment using an aluminum tube.

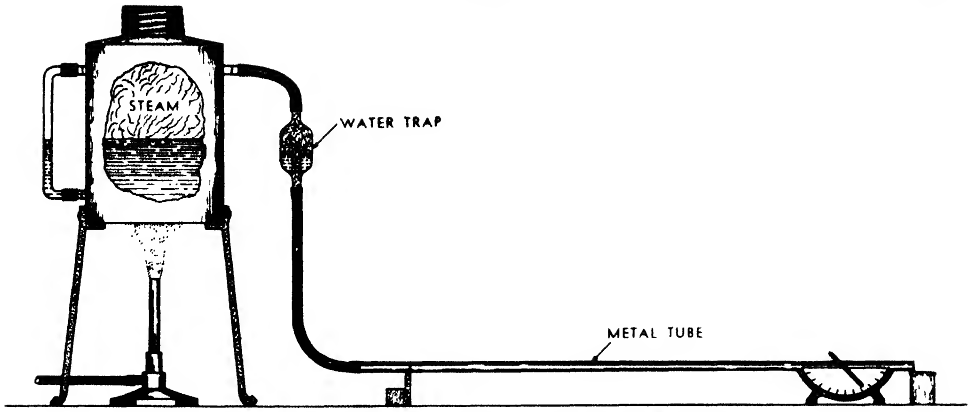

FIG. 255. COEFFICIENT OF LINEAR EXPANSION.

	Brass	*Aluminum*
Length of tube between supports	....	....
Final scale reading	....	....
Room temperature	....	....
Steam temperature	....	....
Diameter of spindle	....	....
Rise in temperature	....	....
Fraction of revolution traveled by pointer	....	....
Total expansion of tube	....	....
Expansion per degree	....	....
Expansion per degree per cm.	....	....
Accepted coefficient of expansion	....	....

TABLE LVI

Questions and Problems:

1. "Coefficient" means ....;

   "coefficient of linear expansion" is the amount one ....

   of length of a solid .... for a rise of ....
   degree(s) in temperature.
2. Why are the rails of a railroad not fitted tightly together by welding?

   ....

   The rails used in a coal mine are welded together. Why is this allowed? ....
3. High power lines are .1 mile between supporting towers. If the wires are copper, how much will they expand when heated by the sun to 100°F from a temperature of 10°F?

4. What is the cause of "piston slap" which is heard when a cold engine is started? ....

....

....

SPECIFIC HEAT

Purpose:

To determine the specific heat of lead and aluminum.

Tools and Materials:

Calorimeter
Thermometer
Steam boiler
Lead cylinder
Aluminum cylinder

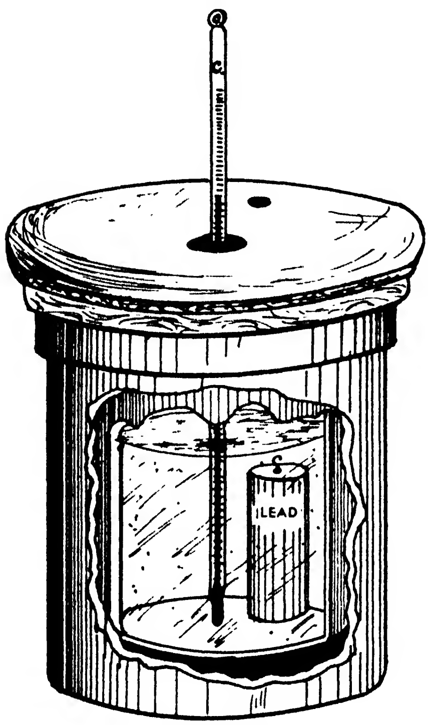

FIG. 256.
CALORIMETER

Procedure:

Weigh the metal cylinders carefully, then place them in boiling water until they are heated throughout to a uniform temperature. Weigh a dry calorimeter cup, then fill it about $\frac{2}{3}$ full of water and reweigh. Measure the temperature of the water in the calorimeter and in the boiler. Quickly remove one of the heated cylinders from the boiling water and place it in the water in the calorimeter, Fig. 256. Stir the water, and record the highest temperature reached. Place all information in Table LVII and calculate the specific heat of the metal. Repeat with the other cylinder.

	Lead	*Aluminum*
Kind of metal cylinder . . .	....	....
Weight of metal cylinder . . .	....	....
Weight of calorimeter . . .	....	....
Weight of calorimeter and water .	....	....
Weight of water	....	....
Temperature of cylinder . .	....	....
Temperature of cold water . .	....	....
Temperature after mixing . .	....	....
Specific heat of calorimeter . .	....	....

Calculations

Weight of cold water in calorimeter .	....	....
Rise in temperature of water . .	....	....
Decrease in temperature of cylinder	....	....
Heat units (calories) absorbed by calorimeter	....	....
Heat units absorbed by water . .	....	....
Total heat units absorbed . .	....	....
Heat units given off by cylinder .	....	....
Heat units given off by one gram of cylinder	....	....
Heat units given off by 1 g. of cylinder cooling 1°C. . .	....	....
Accepted specific heat . . .	....	....

TABLE LVII

Questions and Problems:

1. Heat is produced by impact. Which would have its temperature raised the most, a lead or steel bullet (of the same weight) fired against the target? ....

   Explain ....

   ....

2. Why is water the most efficient liquid to use in a cooling system of an engine? ....

   ....

3. A cooling system of an automobile holds 16 quarts of water. How much heat (B.T.U.) will be needed to raise the temperature of this water from 70°F to 160°F?

4. A 100 g. aluminum cylinder is heated to 100°C and placed in 200 g. of water at 15°C. What is the final temperature of the water?

MACHINES UTILIZE EFFECTS PRODUCED BY CHANGES IN STATE

REFERENCES

Black and Davis: *Elementary Practical Physics*, pages 273-292.
Dull: *Modern Physics*, pages 233-249.
Fletcher: *Unified Physics*, pages 234-253.
Holley & Lohr: *Mastery Units in Physics*, pages 305-320.
Millikan: *New Elementary Physics*, pages 222-277.

MELTING AND FREEZING

All solids are crstalline, i.e. their constituent atoms are arranged in a regular lattice or crystal pattern. Refer to the previous discussion of iron crystals and Fig. 248. If the entire mass is a single crystal, the outward appearance will have the same shape as the space lattice itself (a perfect crystal). This is easily demonstrated by examining crystals of common table salt with a magnifying glass. It will be seen that each crystal is a perfect cube. Some solids such as glass and paraffin are said to be amorphous (non-crstalline), but they in reality, resemble very viscous liquids and are so considered.

A few substances, such as water, antimony and cast iron expand upon freezing. Water and antimony crystallize in the hexagonal space lattice system which seems to account for their increase in volume upon freezing. The bursting of water pipes and engine blocks are common examples of the resulting expansion occuring when water freezes. Type metal, containing antimony, expands upon freezing, making possible the casting of perfect type letters. Cast iron expands slightly when solidifying because of the formation of flakes of graphite. Most metals contract slightly on freezing.

Solids melt at definite temperatures. Substances like glass, wax and butter have no definite melting point. At the melting point, crystalline solids absorb additional heat energy in changing to the liquid state without causing any rise in temperature. This additional heat energy, measured in calories per gram (or B.T.U. per pound) is known as "heat of fusion." (See Fig. 257.) A solid melts and its liquid freezes at the same

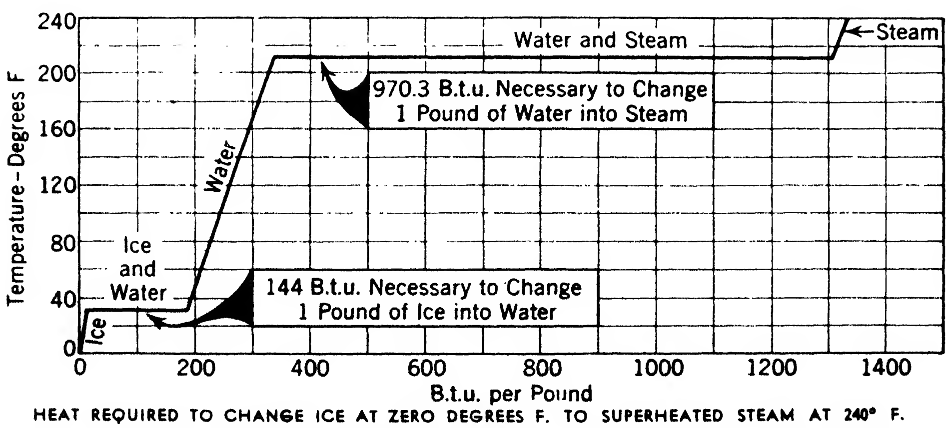

FIG. 257. HEAT REQUIRED TO CHANGE ICE TO STEAM (Courtesy, Johns-Manville.)

temperature. The heat given off when a liquid freezes is known as "heat of solidification." Heat of fusion and heat of solidification for the same substance are equal.

The freezing point of a liquid is lowered by dissolving another substance in it.

The melting of ice by sprinkling salt on it and the use of "antifreeze" solutions in the cooling system of an automobile engine, are applications of this principle.

HEAT OF FUSION OF ICE

Purpose:

To determine how many calories of heat are required to melt 1 g. of ice without changing its temperature.

Tools and Materials:

Calorimeter	Cracked ice
Balance and weights	Towel
Thermometer	

Procedure:

Weigh the empty calorimeter cup, then half fill it with water at a temperature of about 35°C. Reweigh. Read the temperature accurately, then add a few small pieces of ice (the ice must be wiped dry with a towel) and stir the ice-water mixture with the thermometer. Continue adding ice until the temperature has been lowered to about 10°C. When all the ice has melted, read the final temperature accurately. Weigh the calorimeter cup and contents. Record results in Table LVIII.

1.	Weight of calorimeter and water	.... g.
2.	Weight of calorimeter	.... g.
3.	Weight of water	.... g.
4.	Final weight of calorimeter and water	.... g.
5.	Weight of ice added	.... g.
6.	Specific heat of calorimeter	....
7.	Temperature of water (beginning)	.... °C.
8.	Temperature of water (final)	.... °C.
9.	Calories lost by calorimeter	.... c.
10.	Calories lost by water	.... c.
11.	Calories gained by ice (9 + 10)	.... c.
12.	Calories used to heat ice water from 0°C to ....°C	.... c.
13.	Calories used to melt ice (11-12)	.... c.
14.	Calories used to melt 1 g. of ice (heat of fusion)	.... c.
15.	Accepted value for heat of fusion of ice	80 c/g

TABLE LVIII

Questions:

1. The heat absorbed while melting a solid (without changing its temperature) is known as ....

2. When liquids freeze, heat is (absorbed, liberated) ....

   This heat is known as .... and is equal to the heat

   of ....
3. In determining the heat of fusion of ice, why was it necessary to

   dry the ice? ....

   ....
4. Why is ice a good refrigerant? ....

   ....

   ....
5. How many calories will be needed to change 1000 g. of ice (0°C) to water at 20°C?

EVAPORATION

The only difference between an atom (or molecule) of a solid, liquid or gas is the difference in its heat energy. Gaseous atoms or molecules tend to escape from both solids and liquids, this phenomenon being known as evaporation or sublimation (for a solid). A few examples will illustrate some "Laws of Evaporation" commonly encountered.

a) *Increased temperature.* Rain water on a hot street evaporates much more rapidly than rain falling on the same street during a winter day.

b) *Increased area.* Since evaporation (escape of molecules) can occur only at the surface; a quart of water spread out in a shallow pan will evaporate much more rapidly than the same amount of water when allowed to stand in an open milk bottle.

c) *Decreased pressure.* Sugar syrup is evaporated in "vacuum pans"; the water vapor is pumped away from the surface of the sugar liquor to speed evaporation, permitting lower temperatures to be used. The refrigerant in a mechanical refrigerator is allowed to evaporate under reduced pressure.

d) *Humidity.* By humidity, we refer to the amount of water vapor present in the air. When the vapor escaping from a liquid is held in a small air space above the liquid, a state of equilibrium is reached and evaporation is just balanced by condensation. The air in the space above the liquid is said to be saturated. While evaporation (the process) continues, the amount of liquid evaporating in a closed space remains constant, because of condensation.

e) *Circulation.* Clothes dry much quicker in a wind than in still air. This is because the air surrounding the wet clothes cannot become saturated.

f) *Nature of the liquid.* Alcohol, gasoline and ether evaporate much faster than water. Glycerine, motor oil, etc, do not evaporate. This is due to the nature of the molecules which make up these liquids.

BOILING

As heat is added to a liquid, its temperature will rise; this rise in temperature is offset by the cooling effect of evaporation. When these effects balance each other, the liquid boils, and the temperature will not rise further. The boiling point is controlled by the vapor pressure above the liquid, increased pressure raising the B.P. Normal boiling points (100°C and 212°F) are calculated at an atmospheric pressure of 760 mm. of mercury. Dissolved materials raise the B. P. of the solvent.

Demonstration:

Effect of pressure on boiling point.

Fill a Florence (round) flask about ⅓ full of water, clamp on a ring stand and heat over a bunsen flame. When boiling occurs, remove the flame and at the same instant put a rubber stopper in the flask tightly. Turn the flask upside down and pour cold water over the bottom of the flask, Fig. 258. The water boils vigorously while being cooled. Why? Ex-

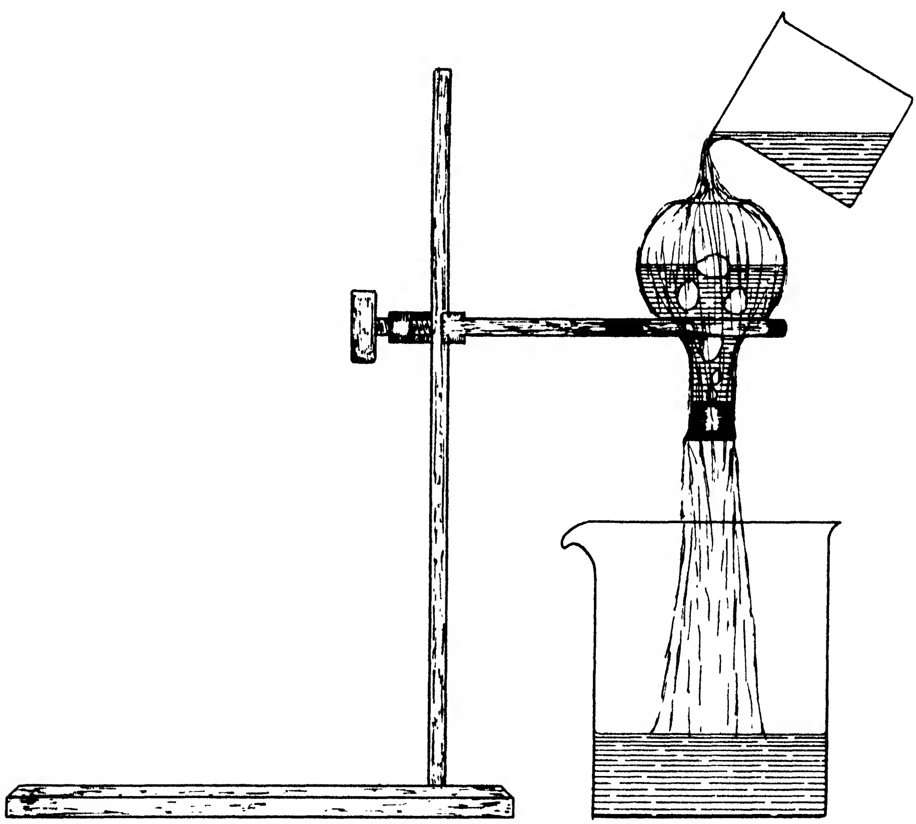

FIG. 258. BOILING WATER BY COOLING.

plain what you have seen. ....

....

....

FINDING THE HEAT OF VAPORIZATION OF WATER

Purpose:

To determine the number of calories of heat needed to change 1 gram of water to steam without increasing its temperature.

Tools and Materials:

Steam boiler	Balance and weights
Water trap	Ice
Calorimeter	Thermometer

Introduction:

When a liquid vaporizes, the energy content of the gaseous atoms or molecules is greater than that of the liquid atoms or molecules at the same temperature. The heat absorbed to give this added energy is known as "Heat of Vaporization." When steam (or other gas) condenses, this additional heat is liberated, and as such is known as "Heat of Condensation." Since heat is required to change a liquid to the gaseous state, evaporation has a cooling effect. This principle, the basis of mechanical refrigeration, is also used by nature to keep the human body cool. The evaporation of body moisture (perspiration) uses up body heat, producing a cooling effect.

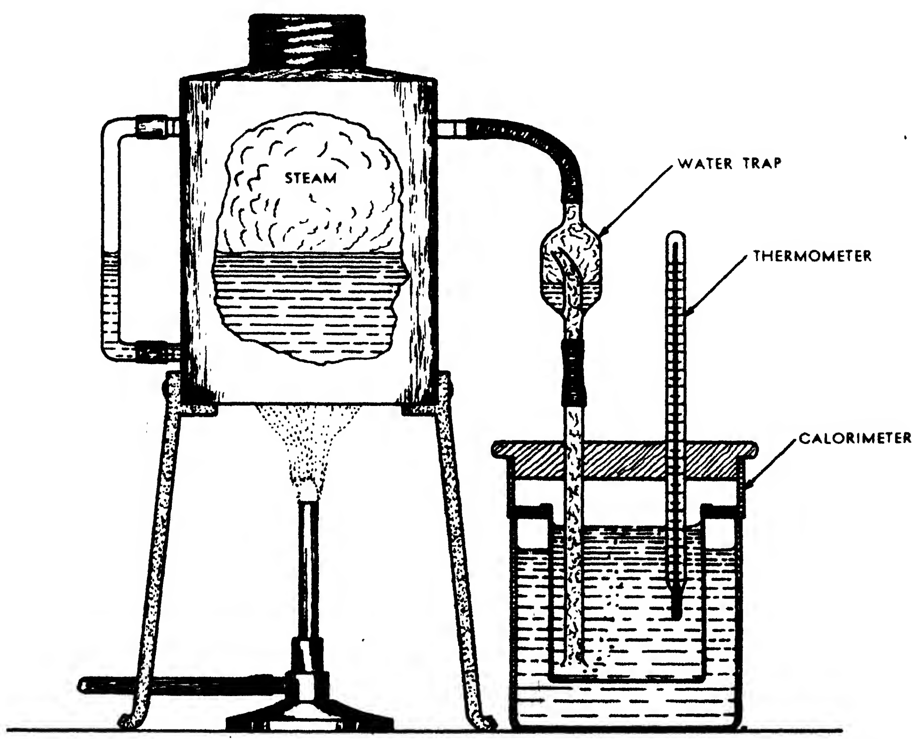

FIG. 259. HEAT OF VAPORIZATION.

Procedure:

Weigh a calorimeter cup, fill it two thirds full of water cooled to about 5°C with ice, then reweigh. Set up the apparatus as shown in Fig. 259. Measure the temperature of the water accurately, then immediately pass steam into the water until the temperature rises to about 35°C. Stir the water and read the final temperature accurately. Weigh the calorimeter cup again, the increase in weight being the weight of the steam which condensed. Read the temperature of the steam in the boiler. Record all results in Table LVIX and complete the calculations called for in the table.

1.	Weight of cold water and calorimeter	.... g.
2.	Weight of calorimeter	.... g.
3.	Weight of cold water	.... g.
4.	Temperature of cold water	.... °C.
5.	Weight of calorimeter, water and steam	.... g.
6.	Weight of condensed steam	.... g.
7.	Temperature of steam	.... °C.
8.	Temperature of steam and water mixture	.... °C.
9.	Increase in temperature of cold water	.... °C.
10.	Heat gained by cold water	.... c.
11.	Heat gained by calorimeter (Sp. Ht. ....)	.... c.
12.	Total heat gained	.... c.
13.	Drop in temperature of steam	.... °C.
14.	Total heat lost by steam	.... c.
15.	Heat lost by condensed steam	.... c.
16.	Heat lost by condensation	.... c.
17.	Heat lost by 1 g. steam in condensing	.... c.
18.	Accepted value for Heat of Vaporization or Heat of Condensation	537 c/g

TABLE LVIX

Questions:

1. Why was the water trap used? ....

....

....

2. Suggest a reason why water is the best liquid for cooling an internal combustion engine. ....

....

3. Liquid ammonia has a high heat of vaporization (295 c/g). Why is this fact important in refrigerating systems using ammonia? ....

....

....

MACHINES APPLY THE PRINCIPLES OF EVAPCRATION AND CONDENSATION

The steam engine (Fig. 28) operates on the energy of steam as it expands in the cylinder. The steam is generated in a boiler, as water (liquid), is evaporated by the absorption of heat energy.

The basic principle of mechanical refrigeration is that heat is extracted from surrounding material by the evaporation of a volatile liquid. To make the process of refrigeration continuous, the evaporated refrigerant must be converted back into the liquid state by condensation. Two principal systems used in mechanical refrigeration are the Absorption and the Compression systems. The absorption system is suited to industrial installations where very low temperatures are required, but more often the compression system is used. The absorption system is more commonly used in smaller refrigerating units, where it is particularly efficient since it has no moving parts to wear and make noise. "Molecules do not wear out." The following explanation of a refrigerating cycle using the absorption principle is given by permission from Servel, Inc.

REFRIGERATION

The refrigerating unit, Fig. 260, is made up of a number of steel vessels and pipes welded together to form a hermetically sealed system. All the spaces of the system are in open and unrestricted communication so that all parts are at the same total pressure.

The charge includes an aqua-ammonia solution of a strength of about 30% concentration (ammonia gas to water by weight) and hydrogen gas. For a unit of sufficient capacity for a 5 cu. ft. cabinet, the approximate charge is: 1.5 lbs. ammonia; 3.5 lbs. water; 0.01 lbs. hydrogen. The liquid is charged into the unit as a solution and then the hydrogen is added.

The elements of the system include a generator (1) (sometimes called boiler or still), an ammonia condenser (2), an evaporator (3), an absorber (4), and a hydrogen reserve vessel (5). There are three distinct fluid circuits in the system. An ammonia circuit including the generator, condenser, evaporator, and absorber; a hydrogen circuit including the evaporator and absorber; and a solution circuit including the generator and absorber.

Starting with the generator, heat is applied by a gas burner or other source of heat to expel ammonia from solution. The ammonia vapor thus generated flows upwardly to the ammonia condenser. In the path of flow of ammonia from the generator to the ammonia condenser are interposed an analyzer (6) and a rectifier (7). Some water vapor will be carried along with the ammonia vapor from the generator. The analyzer and rectifer serve to remove this water vapor from the ammonia vapor. In the analyzer, the ammonia passes through a strong solution which is on its way from the absorber to the generator. This reduces the temperature of the generated vapor somewhat to condense water vapor without condensing ammonia, and the resulting heating of the strong solution expels

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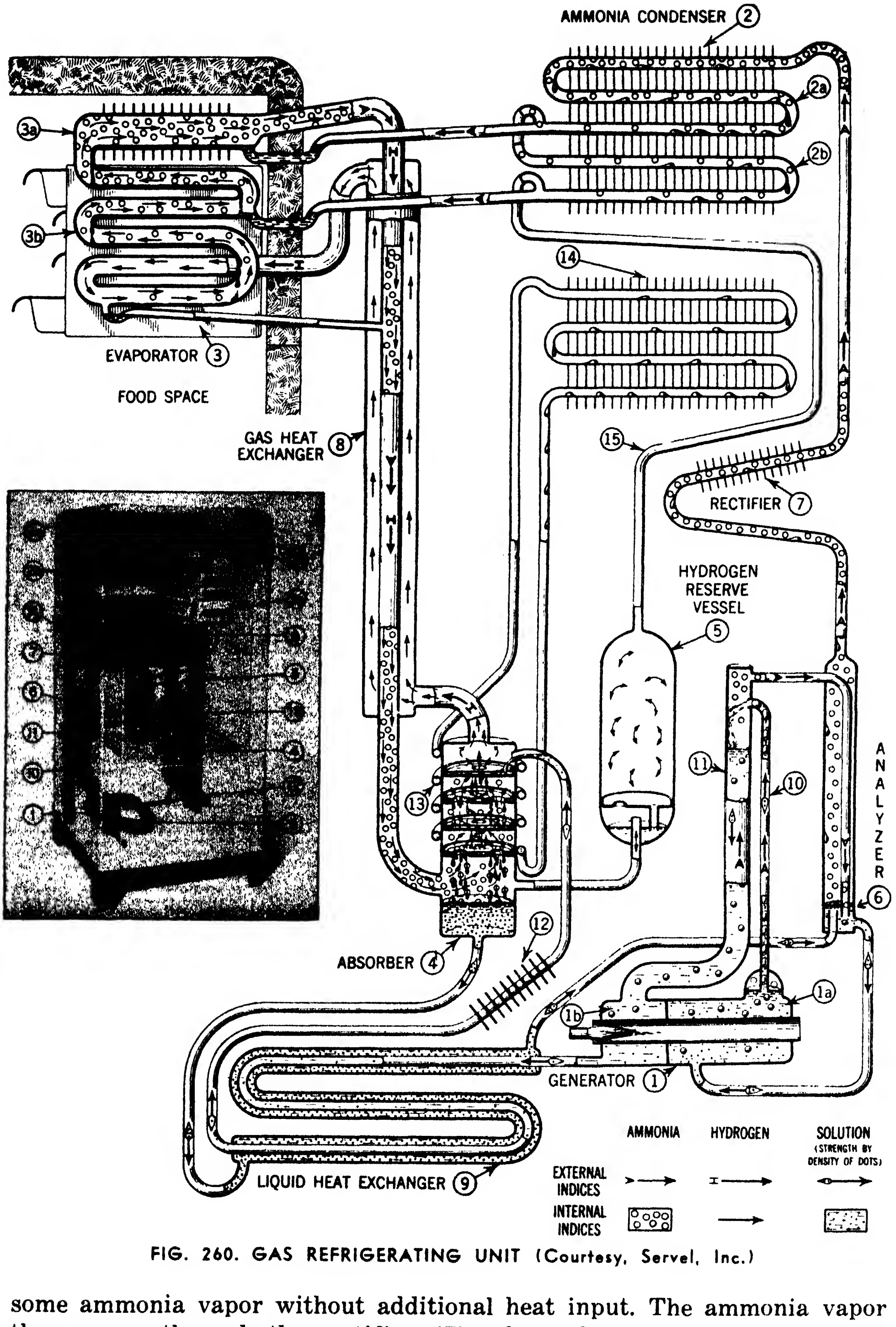

FIG. 260. GAS REFRIGERATING UNIT (Courtesy, Servel, Inc.)

some ammonia vapor without additional heat input. The ammonia vapor then passes through the rectifier (7) where the residual small amount of water vapor is condensed by atmospheric cooling and drains to the generator (1) by way of the analyzer (6).

The ammonia vapor, which is still warm, passes on to the upper section (2a) of the ammonia condenser (2) where it is liquefied by air

cooling. The ammonia condenser is provided with fins for this purpose. The ammonia thus liquefied flows into the upper evaporator section (3a). A liquid trap is interposed between the ammonia condenser and the upper evaporator section (3a) to prevent hydrogen from entering the condenser. The upper evaporator section (3a) is provided with fins and directly cools the food space.

Ammonia vapor which does not condense in the upper section passes to the lower section (2b) of the ammonia condenser and is liquefied and flows through another trap into the lower ice freezing evaporator section (3b).

Hydrogen gas enters the lower evaporator section (3b) and, after passing through a precoöling pipe part, flows upwardly, in counterflow to the downwardly flowing liquid ammonia. The effect of the placing of a hydrogen atmosphere above the liquid ammonia in the evaporator is to reduce the partial pressure of the ammonia vapor in accordance with Dalton's law of partial pressures. While the total or gage pressure in the evaporator and the pressure in the condenser are the same, there is substantially pure ammonia in the space where condensation is taking place and consequently the vapor pressure of the ammonia substantially equals the total pressure. Under Dalton's law, the total pressure of a gas mixture is equal to the sum of the partial pressures of the individual gases. Consequently in the evaporator the partial ammonia vapor pressure is less than the total pressure by the value of partial pressure of the hydrogen. The lesser ammonia vapor pressure results in evaporation of the ammonia with consequent absorption of heat from the surroundings of the evaporator and the cooling of the surroundings which are in a well-insulated enclosure.

The cool heavy gas mixture of hydrogen and ammonia vapor formed in the evaporator leaves the top of the evaporator and passes downwardly through the center of the gas heat exchanger (8) to the absorber (4). In the absorber, ammonia is absorbed by water, and the hydrogen, which is practically insoluble, passes upwardly from the top of the absorber through the external chamber of the gas heat exchanger (8) into the evaporator. Perfect separation of gases is of course not possible and some ammonia vapor passes with the hydrogen from the absorber to the evaporator. It is probably more accurate to call the gas flowing from the evaporator to the absorber strong gas (hydrogen strong ammonia) and call the gas flowing from the absorber to the evaporator weak gas (hydrogen weak in ammonia).

Since the weight of a gas is proportional to its molecular weight and the molecular weight of hydrogen is 2, it follows that the specific weight of the strong gas is greater than that of the weak gas. This difference in specific weights is alone sufficient to initiate and maintain circulation between the evaporator and the absorber. Since the absorber is below the evaporator, it is possible to have upward gas flow in the evaporator. The long vertical column of strong gas in the central chamber of the gas heat exchanger is heavier than the vertical column in the absorber, external heat exchanger space and evaporator, despite the fact that the gas in the evaporator is heavy. Consequently the gas will flow as above stated due

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to the difference in specific weights of the gases in the different vertical branches of the circuit. The gas heat exchanger transfers heat from the weak gas to the strong gas. This saves some cooling in the evaporator by pre-cooling the entering gas. A liquid drain at the bottom of the evaporator is connected to the downflow space of the gas heat exchanger.

Counter-current flow in the evaporator permits the location of the box cooling section of the evaporator in the most effective position, at the very top of the food space. Also, the gas leaving the lower temperature evaporator section (3b) can pick up more ammonia at the higher temperature prevailing in the box cooling evaporator section (3a), thereby increasing capacity and efficiency. There is still another advantage in that liquid ammonia flowing to the lower temperature evaporator section is precooled in the upper evaporator section.

The dual liquid connection between the condenser and the evaporator is advantageous in applying the unit to the cabinet. It permits extending the ammonia condenser below the top of the evaporator to provide more surface while having gravity flow of liquid ammonia to the evaporator.

The two-temperature evaporator partially segregates the ice freezing function from the box cooling function. This provides a better humidity condition in the food space because, due to the higher temperature of the box cooling section (though adequately low for proper preservation), less moisture is extracted to form frost.

In the absorber, a flow of weak solution (water weak in ammonia) comes in direct contact with the strong gas. The liquid and gas flow in counter-current. The weak solution is thus enriched or strengthened while the strong gas is weakened.

From the absorber, the strong solution flows through the liquid heat exchanger (9) to the analyzer (6) and thence to the strong liquid chamber (1a) of the generator (1). Heat applied to this chamber causes vapor and liquid to pass upwardly through the small diameter pipe (10), as in an "air lift" to the weak solution stand-pipe (11). Liberated ammonia vapor passes to the ammonia condenser as above described. The solution flows down through pipe (11) to the weak liquid chamber (1b) of the generator. Here further vapor is driven off which passes upwardly through the down-flowing liquid in the stand-pipe (11). The weak solution flows through the liquid heat exchanger (9) and to the absorber. The liquid heat exchanger precools the liquid entering the absorber and preheats the liquid entering the generator. Further pre-cooling of the weak solution is obtained in the finned air cooled loop (12) between the liquid heat exchanger and the absorber.

The heat which is liberated by absorption of ammonia in the absorber is carried away by a small quantity of volatile fluid in the coil (13) surrounding the absorber. The resulting vapor rises to a secondary condenser (14) and is there liquefied, the liquid returning by gravity to the coil (13). This enables an advantageous positioning of air-cooled surface and absorber respectively.

The hydrogen reserve vessel (5) is interposed in the equalizing or vent tube (15) and may be described as a reservoir for hydrogen gas while the refrigerator is operating under normal room temperature con-

ditions. Under these conditions an appreciable part of the hydrogen in the system is stored in the reserve vessel. The remainder is located in the evaporator-absorber circuit and serves to balance the condenser pressure. This pressure must of course be adequate to liquefy the ammonia gas in the condenser. If the pressure is increased, the efficiency under normal conditions will be impaired, and yet it is necessary to have a higher pressure in the system to insure condensation of the ammonia under high room temperature conditions. The reserve vessel and its connection in the system is an automatic pressure variant to take care of the variable room temperature and loads and to permit lower operating pressure at lower room temperature, thereby resulting in better efficiency and higher operating pressure under extreme conditions to insure condensation of ammonia. It operates in the following manner:

Should the room temperature rise materially, ammonia vapor fails to condense in adequate quantity and some vapor flows through the equalizing tube (15). Thus additional ammonia vapor is liberated by the generator and is pushed through the condenser and into the reserve vessel, displacing the hydrogen therein, which is in turn pushed into the active part of the system. The hydrogen is actually transferred from the reserve vessel through a pipe into the absorber and then distributes itself in the evaporator-absorber circuit. This displacement of hydrogen by ammonia and the re-distribution of hydrogen has a double effect. The pressure in the system is increased due to the additional ammonia gas present. This results in an adequate condensing pressure at the higher room temperature. At the same time the additional hydrogen in the evaporator serves to balance the increased condenser pressure without increasing the partial pressure of ammonia in the evaporator. Without this additional hydrogen it would be necessary to balance the increased pressure by raising the ammonia pressure in the evaporator which would result in an undesirable increase in evaporator temperature. When the room temperature decreases again, the more effective condensation in the condenser causes the ammonia gas to return from the reserve vessel to the ammonia condenser and hydrogen (weak gas) flows from the absorber into the reserve vessel.

It is possible to further improve performance by providing for automatic variation of the ammonia solution strength. This method employed is similar to that of the hydrogen reserve vessel in that a reservoir or chamber for the storage of liquid ammonia is provided. This is located at the bottom end of the hydrogen reserve vessel. For the sake of efficiency it is desired that the strongest solution consistent with good operation be used under normal room conditions. Yet is is desirable to reduce this concentration if efficient absorption is to be obtained at high room temperatures. To accomplish this, ammonia must be automatically removed from solution and stored somewhere in the system as liquid ammonia. When the extreme conditions are experienced, some of the ammonia which passes into the hydrogen reserve vessel condenses on the inner walls of the vessel and drains to the bottom. It collects at this point and is effectively removed from the active part of the system, thereby reducing the concentration of the ammonia in solution. As soon as normal conditions return, hydrogen flows into the reserve vessel and the liquid ammonia

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stored in the bottom of the vessel evaporates and is returned to the solution in the absorber by diffusion.

As refrigeration load increases, a thermostat functions to increase the flow of gas to the burner which causes a greater amount of ammonia to be expelled, condensed, and evaporated per unit of time.

COMPRESSION SYSTEM

Two commonly used types of compressors used in this system are (1) the reciprocating piston type and (2) the rotary type. The gas used as the refrigerant is compressed, the heat caused by compression being removed by air or water cooling systems, and the vapors condensed into a liquid. The liquid then passes through an expansion valve into the expansion or evaporator coils, where the reduced pressure causes the liquid to evaporate. The heat necessary to cause this evaporation is taken from the surrounding materials (brine in industrial installations, or the air in a storage room or in a domestic refrigerator). The compressor then draws the vaporized refrigerant from the evaporating coils, compresses it and the cycle is repeated. The part of the system (compressor, condenser and lines up to the expansion valve) where the refrigerant is kept under high pressure is called the high pressure side; that part which

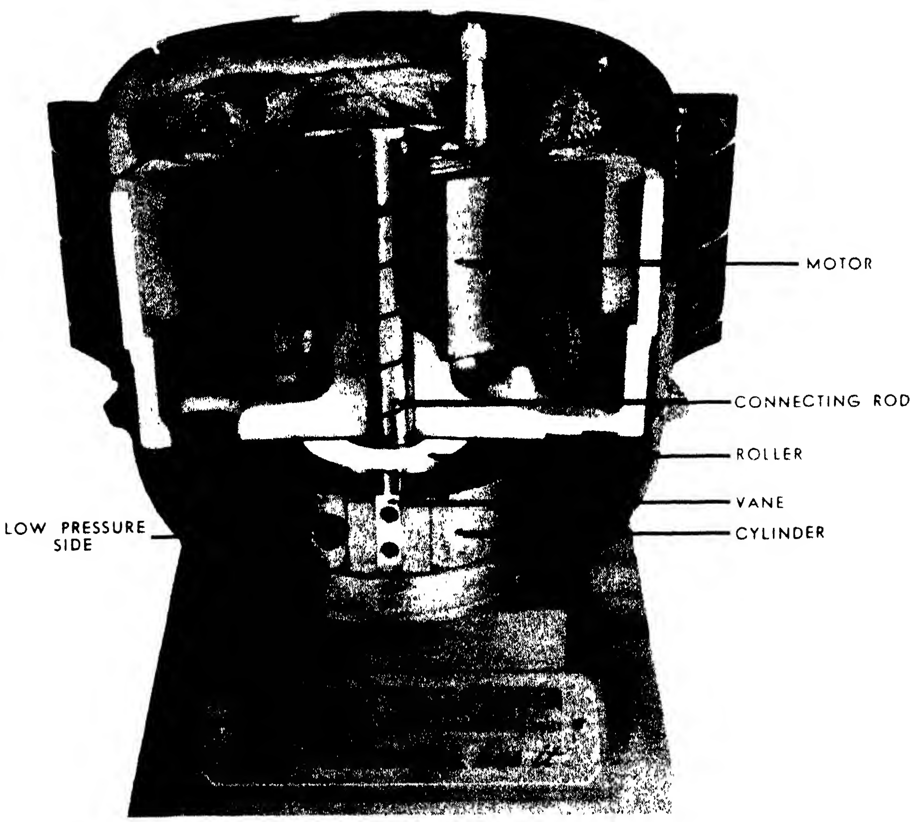


FIG. 261. ROTARY COMPRESSOR.

handles the low-pressure vapors (expansion valve and evaporator) is known as the low pressure side.

The reciprocating compressor resembles the piston and cylinder of an internal combustion engine. The piston is moved by a crankshaft connected to the drive shaft of the driving motor or engine. Suction and discharge parts of the system are divided by valves. A rotary compressor as used in some domestic refrigerators, room coolers and water coolers is shown in Fig. 261. This type of compressor is desirable in small installations because of its small number of moving parts and freedom from vibration. Pressure is produced by the rotation of an eccentrically driven roller within a casing. This roller progresses around the inner circumference of the cylinder and makes contact at one point with the cylinder wall and at another point with a vane. The vane is held in a fixed position and separates the suction side (low-pressure side) from the discharge side (high-pressure side) of the cylinder. During rotation, the roller compresses the entrapped gas ahead of it between the cylinder wall, the vane and the roller. A spring keeps the vane in contact with the surface of the roller. Lubricating oil serves as a seal between the roller and the housing, and as protection against wear of moving parts.

Questions:

1. Two types of refrigerating systems are the .... and the .... systems.
2. In the compression system the refrigerating cycle is made continuous by the action of a ....; in the absorption system .... energy is used to transfer the refrigerant from the low-pressure side to the high-pressure side.
3. Two commonly used types of compressors are the .... and the ....
4. Gaseous refrigerants are liquefied by .... and ....
5. Heat is (liberated, absorbed) .... when the refrigerant is condensed and .... when the refrigerant evaporates.
6. Ice, used in non-mechanical refrigerators, is a good refrigerant because its heat of fusion is .... This means that ice ....

HEAT TRANSFER IS ESSENTIAL IN HEAT ENGINES

REFERENCES

Black and Davis: *New Practical Physics*, pages 255-268.
Dull: *Modern Physics*, pages 254-269.
Fletcher: *Unified Physics*, pages 213-229.
Holley & Lohr: *Mastery Units in Physics*, pages 321-332.
Millikan: *New Elementary Physics*, pages 279-293.
TM-10-570 *Internal Combustion Engines*, pages 92-102.

A. CONDUCTION

Heat must be transferred from one place to another in order that it may be utilized. It must also be transferred if it's accumulation would prevent efficient operation of machinery. The transfer of heat requires a knowledge of methods by which heat moves. Since heat is a manifestation of molecular motion, the kinetic molecular theory is used to explain the movement of heat through matter and space.

Molecules are in constant motion and are constantly colliding with one another. When molecules collide, energy is transferred. When the temperature of a material is raised at a certain point, the molecules move with greater rapidity, colliding with adjacent molecules. The energy producing this increased motion is thus handed from one molecule to the next. If one end of a metal rod is heated the molecules of the hot end move more rapidly. In turn, they collide with molecules adjacent to them, causing them to move more rapidly. The heat eventually is transmitted along the rod by molecular motion. This is transfer of heat by conduction.

Not all substances are good conductors of heat. The metals, in general,

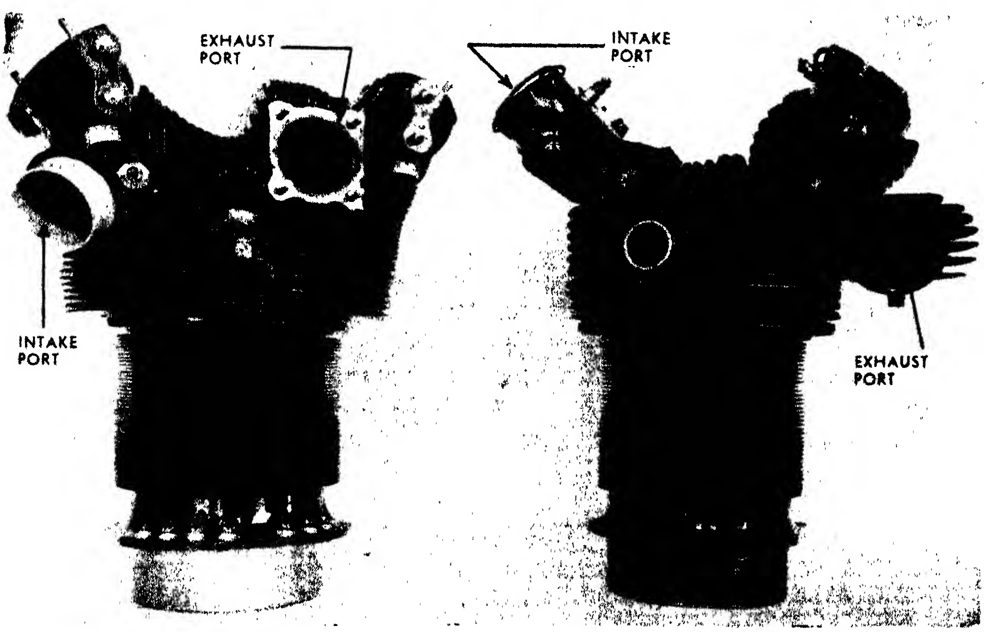


FIG. 262A. CYLINDERS OF WRIGHT WHIRLWIND ENGINE.

are the best conductors of heat; silver, copper, aluminum and iron, heading the list. Porous solids such as cork, wood, and textiles conduct heat very poorly. The rate of conduction may be measured, this serving as a means of determining the actual conductivity of heat by substances. It is very noticeable that some objects in the same room seem to have different temperatures. The rugs and chair coverings feel warm to the touch, while linoleum, tile floors and metal objects seem cold. When heat is conducted away from the body rapidly, an object feels colder than if the heat is conducted away slowly. The rate of conduction depends upon the molecular makeup of the substance.

To keep the operating temperature of air cooled airplane engines within safe limits, an ingenious arrangement of cooling fins is made on the surface of the cylinder barrel and cylinder head. The improvement in fin design in the Wright Whirlwind engine during the past few years is shown in Fig. 262A. An engine made with the new type cylinder will develop more than twice the horsepower of the older type. This is due to a higher compression ratio and better cooling. The fins on the new type cylinder have a surface area of 3600 square inches. and, being made of metals which are good conductors, they conduct the heat away from the cylinder rapidly. It is interesting to note the absence of fins around the intake port and the additional ones around the exhaust port.

The following table of Thermal Conductivities is printed by permission from the Johns-Manville Co., taken from their booklet *Heat.*

THERMAL CONDUCTIVITIES

k = B.t.u. in./hr./sq. ft./degrees F.

Substance	*Temperature degrees F.*	*k*
Silver	212	2880
Copper (pure)	212	2664
Aluminum	212	1424
Brass (60-40)	212	828
Zinc	212	744
Tin	212	408
Steel (mild)	212	396
Cast iron	212	336
Lead	212	237
Ice	32	15
Sandstone	104	12
Dolomite	122	12
Concrete (stone)	......	.6
Oak	122	3
Diatomaceous Silica (natural)	212	0.6
85% Magnesia	212	0.49

Demonstration:

Varying conductivities of metals

The rate of heat conduction by various metals may be shown by the use of an apparatus similar to that shown in Fig. 262B. Rods of different

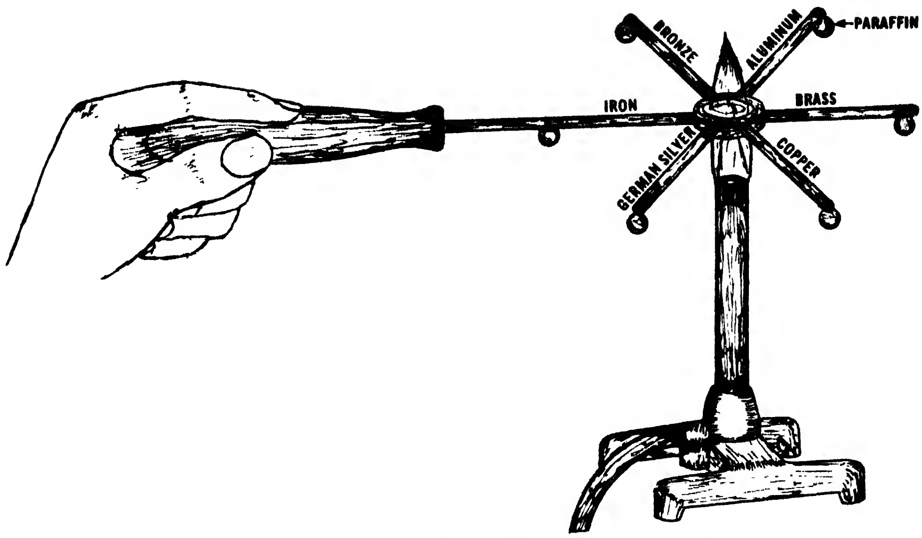


FIG. 262B. HEAT CONDUCTIVITY.

metals having the same diameter are heated uniformly on one end. The heat is conducted to the other end of the rod at varying rates according to the ability of the metal to transfer it. The time required for each metal to conduct the heat can be determined by observing the time required to melt the wax ball placed on the end of each rod.

Questions:

1. From observations made, name the metals used in the order of their conductivity, beginning with the best conductor.

   a) .... *b)* .... *c)* ....

   d) .... *e)* .... *f)* ....

2. The *time* required for the heat to be conducted depends upon ....

   ....

3. The *direction* in which the heat is conducted depends upon ....

   ....

Another effective demonstration of the varying heat conductivities of materials is to place a rod of copper and one of wood, end to end, wrapping them with a layer of heavy paper. Heat the rods in a bunsen flame which has been spread out by means of a wing top. The paper about the wood will catch on fire almost instantly but that about the copper remains unburned for some time, due to the rapid conduction of heat away from the paper by the copper.

It may be shown that water is a poor conductor of heat by placing an ice cube in the bottom of a large test tube, filling the tube three-fourths full of water, and heating the water in the top of the test tube. (Note: the ice can be held at the bottom of the tube by means of a wad of steel wool). It will be found that the water in the top of the test tube can be boiled without changing the melting rate of the ice cube.

INSULATION

Gases are poor conductors of heat. The low conductivity of gases can be demonstrated by measuring the conductivity of a solid substance before and after breaking it into extremely fine particles. The conductivity of the latter will be found to be far less than the first measurement because of the numerous air spaces (pores) between the solid particles. Wool clothing, feathers, furs, rock wool, spun glass, ground cork — are all poor conductors of heat because of their large pore space content.

Within the last twenty years the general public has been educated to the economy and comfort derived from the proper use of insulating materials. As a result, many homes, public buildings, factories and vehicles have been insulated. In homes, the refrigerator, hot water storage tank, cook stove oven, furnace pipes, water coolers and similar devices conserve heat by proper insulation. Insulation reduces fuel bills, cuts down consumption of electrical power, and adds to the comfort and convenience of homes.

Insulators, being poor conductors of heat, prevent heat from escaping or entering a closed space. Insulating materials are usually light, porous, non-inflammable solids, made up in various forms for use. Asbestos in the form of fiber, wool and paper, is a much used insulator. Rock wool, spun glass and 85% Magnesia are other popular types of mineral insulation. Fig. 263 shows how rock wool, in nodulated form, is blown into hollow walls and attic spaces of a building already constructed. In new construction, rock wool is applied in the form of "batts" as shown in Fig. 264. The process of placing 85% Magnesia Lagging, as an insulating material on a locomotive boiler, is shown in Fig. 265.

FIG. 263. IN EXISTING HOMES ROCK WOOL IN NODULATED FORM, IS BLOWN UNDER PRESSURE INTO HOLLOW WALLS AND ATTIC SPACES. (Courtesy, Johns-Manville.)

FIG. 264. FOR NEW CONSTRUCTION, ROCK WOOL IS APPLIED IN THE FORM OF BATTS. (Courtesy, Johns-Manville.)

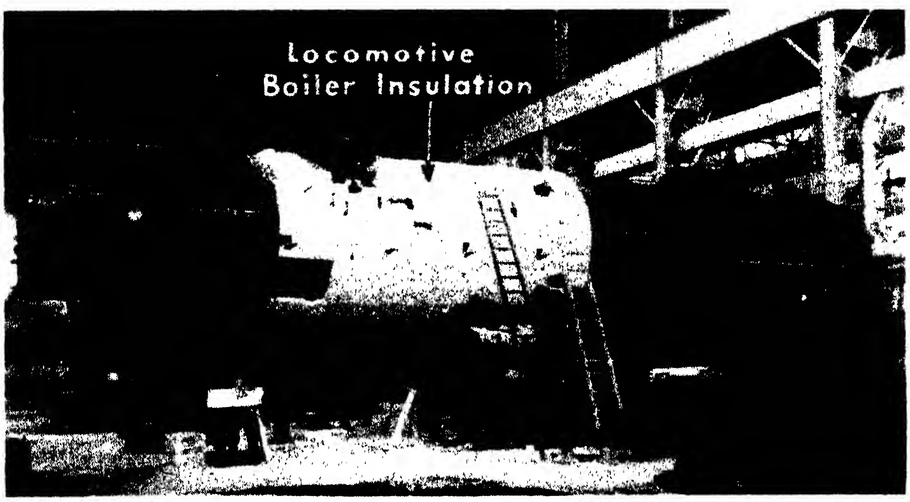


FIG. 265. J-M 85% MAGNESIA LAGGING BEING INSTALLED ON THE BOILER OF A LOCOMOTIVE. (Courtesy, Johns-Manville.)

Questions:

1. When substances are heated, the .... move faster and the temperature rises. The kinetic molecular theory explains how heat is conducted from one place to another, by stating that heat energy is passed from .... to ....

in the direction from point of higher .... to the point of lower ....

2. Metals are classed as the .... conductors of heat. Listed in order of heat conductivity, the four best metal conductors are (1).............................. (2).............................. (3).............................. (4) ....

3. In general, ... and .... are poor conductors of heat. A very poor conductor of heat may be classed as a(n) .... Some of the very poor conductors of heat used as insulators are (1).............................. (2).............................. (3) .... (4).. .

In addition to being a poor conductor, a good insulator should also be .... In general, those solids which are poor conductors of heat are ....

4. A building may be insulated in the following ways: (1) .... (2).. (3)..

5. A radial airplane engine is cooled by .... on the outside of the cylinder walls. An automobile engine is cooled by a ....

In steam boilers, the heating area is increased by the use of .... through the boiler. Heat passes from the .... to the water by ....

B. CONVECTION

The molecules in liquids and gases move about freely. Liquids and gases, because of this freedom of molecular movement, can transfer heat from one place to another by convection. By convection, we mean a circulation of fluid, carrying heat.

When water is heated in a pan over a fire, the liquid next to the bottom receives heat first. The heated water expands and rises. Colder water from the top of the pan being heavier, settles to the bottom, is heated, becomes less dense and rises to be cooled. Alternate heating and cooling sets up a circulation within the body of the liquid. The hot water in the home storage tank operates on this principle.

Gases act in very much the same manner. A mass of air may become heated, grow less dense and rise. Cooler air from the upper atmosphere flows downward, is heated and rises to be cooled. This alternate heating and cooling causes up drafts and down drafts in the atmosphere. Birds and gliders soaring, find the up drafts very useful. Aviators report these up drafts many thousands of feet in altitude.

These great convections of air, along with the wind, keep the air well stirred. In fact, wind itself is a part of a great convection, blowing toward a low pressure area which has been caused by heated air "up drafts."

Chimneys, smoke stacks, ventilators, and ship funnels serve the purpose of producing a convection current of gas. All operate on the principle that heated air, being less dense, rises, and rising, provides space for other gas. These currents circulate heat as well as gas. Hot air furnaces and air conditioners use convection in carrying out their functions.

Demonstration:

A beaker of water can serve to demonstrate convection currents. A liter beaker filled with cold water is set on a ring stand. The flame of a bunsen burner is directed on the bottom of the beaker, near the edge. After the flame has heated the water for a minute or two, sprinkle a pinch of powdered potassium permanganate or some highly colored dye on the surface of the water. Watch the currents of water circulate the colored material about in the beaker.

To observe convection currents, strike a pair of dusty erasers together near the top of a hot air register or steam radiator and watch the path taken by the dust circulation.

COOLING SYSTEMS

The automobile engine is cooled by a forced convection system. In Fig. 266 it can be seen that the engine block is cast with a double wall so that cylinder walls and valve ports are surrounded by a jacket of circulating water. Reserve water is held in the radiator. The water becomes heated about the cylinder walls, rises to the top of the block and finds its way out

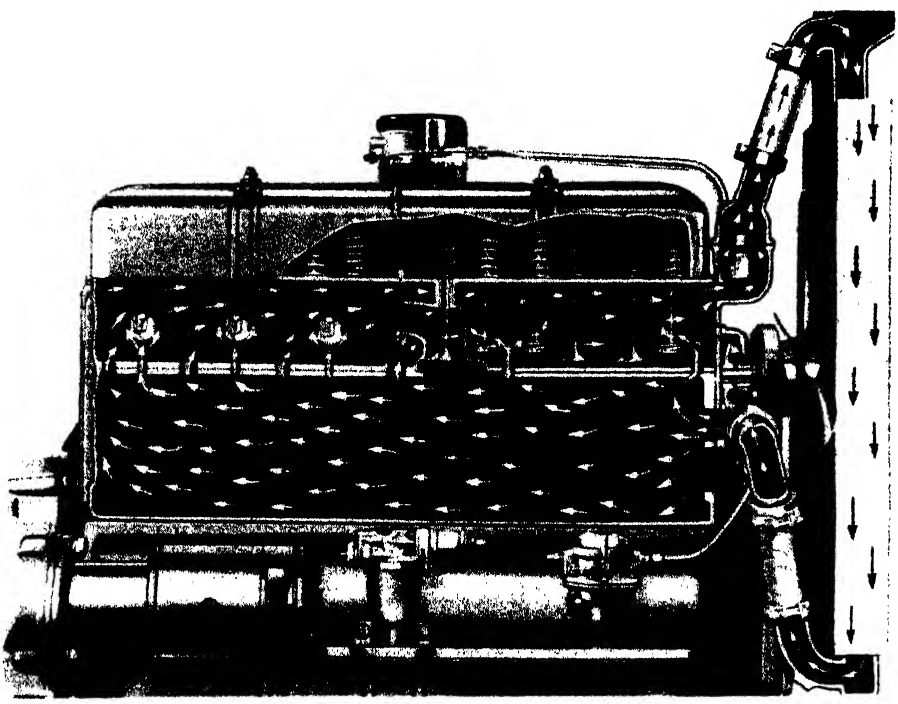


FIG. 266. COOLING SYSTEM. (Courtesy, Chevrolet Division, General Motors Corporation.)

of the block to the radiator through the top hose. In the radiator, the water is cooled as it passes through a honeycomb of metal. The cold water settles to the bottom of the radiator, passes through a hose to the engine block, completing the cycle. A water pump is used to circulate the water faster. When water evaporates from the radiator, the level may not be high enough to allow water to reach the radiator by convection, therefore a pump is used to insure proper circulation.

Questions:

The .... which make up liquids and gases, are free to move. In convection, the heated molecules .... the heat energy from one place to another. Heated liquids and gases rise because they become .... A current, produced in a body of gas or liquid by a difference in their density, is called a .... current.

C. RADIATION

The third method of heat transfer is by radiation. Heat, like light and sound, is a form of vibrant energy. When the molecules of a substance are heated, violent disturbances occur in their molecular structure. Waves of heat energy are sent out in all directions. The wave length of this energy is a little longer than light waves but not as long as sound waves.

The vibrant energy of heat, while it is invisible, can be reflected by a hard, bright surface. A parabolic mirror can reflect heat in a given direction or can receive heat rays and focus them at a point in space.

The radiometer, Fig. 244, demonstrates the effect of radiant energy. Enclosed in a glass bulb, the rotating vanes cannot be affected by convection currents or conducted heat. A hot body brought near the radiometer causes it to whirl rapidly.

The condition on the surface of a body determines whether or not it is a good radiator of heat. Bodies whose surfaces are rough and dark, are the best radiators. Those whose surface is smooth, hard and light in color are the poorest radiators. These facts may be demonstrated by using two air thermometer bulbs. See Fig. 267. Black one with soot from burning camphor; paint the other one white or with aluminum paint. Dip the end of each in a beaker of colored water. Place a bunsen burner flame equidistant from each one and heat them uniformly. From which bulb do the air bubbles leave more rapidly? ....

Why? ....

Now allow the bulbs to cool. Which one draws water up the tube more rapidly? What are your conclusions ....

....

HEAT TRANSFER IN A STEAM BOILER

In steam boilers heat must be transferred from the fire to the water as quickly and efficiently as possible. The heat energy passes to the boiler

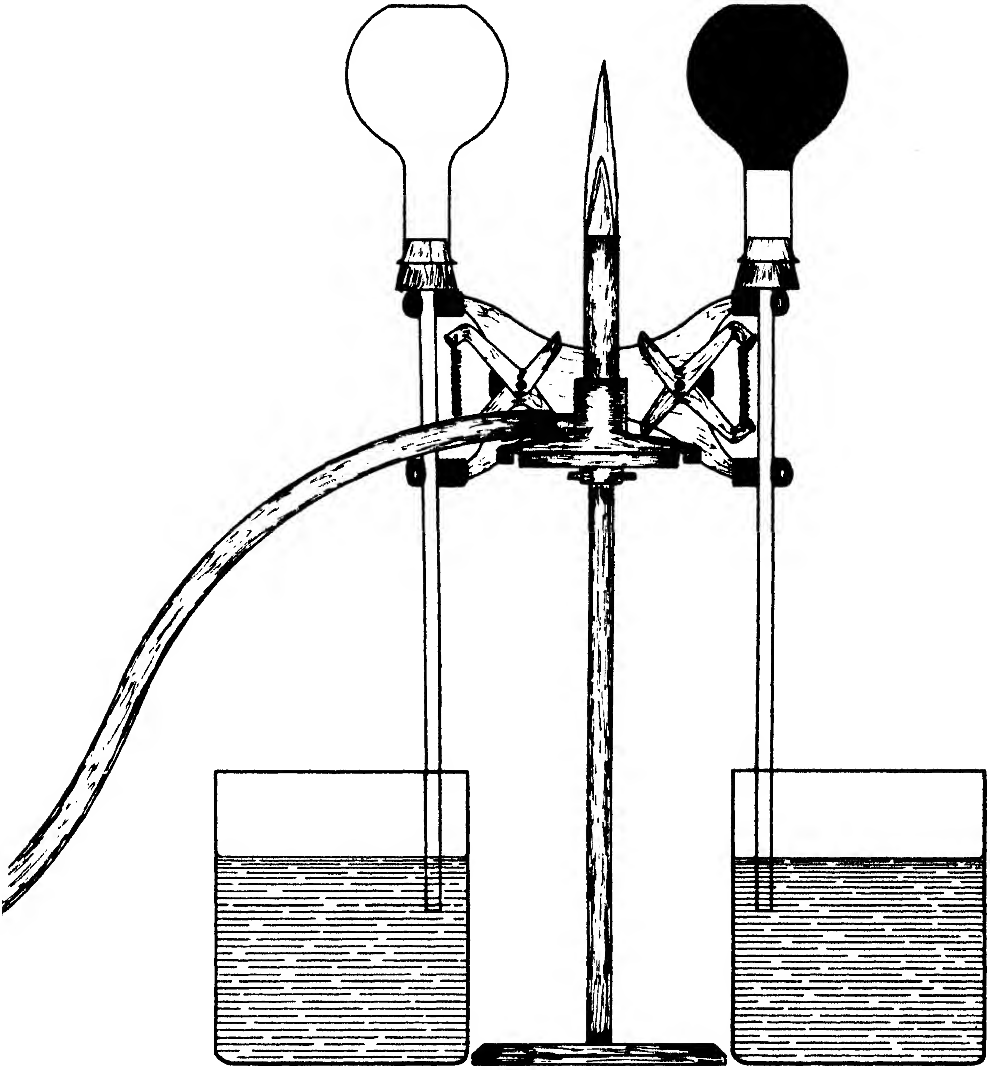


FIG. 267. AIR THERMOMETERS.

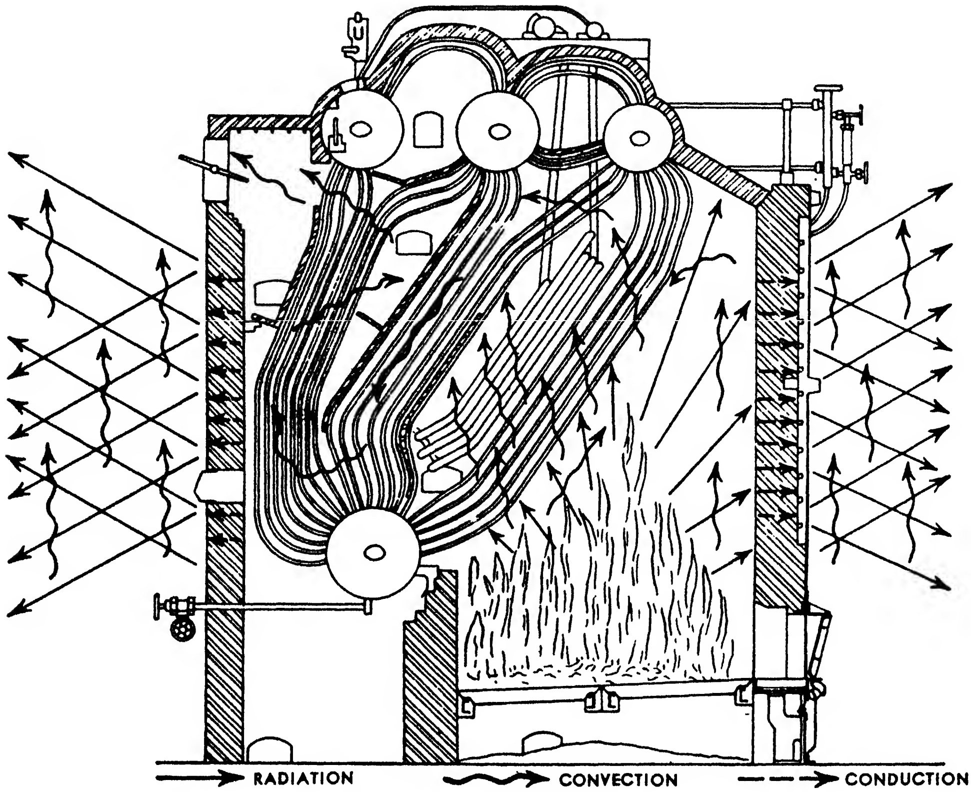
tubes by radiation and convection; and through the tube walls by conduction. The water in the tubes transmits the heat by convection. See Fig. 268. If the boiler is not properly insulated so as to conserve as much heat as possible, a great deal of heat loss results from radiation and convection to the boiler wall; conduction through the boiler wall; and radiation and convection outside the wall.

The rate at which heat is transmitted by conduction through the wall varies directly with the area of the wall, the temperature difference between the hot and cold surfaces of the wall, the thermal conductivity of the materials of which the wall is composed and inversely with the thickness of the wall.

RADIATION

Purpose:

1. To study radiation of heat from the surface.



HEAT IS TRANSFERRED IN A BOILER BY RADIATION, CONDUCTION AND CONVECTION, AS SHOWN BY THE THREE TYPES OF ARROWS IN THIS ILLUSTRATION. IF THE BOILER IS NOT PROPERLY INSULATED A GREAT DEAL OF HEAT IS LOST THROUGH RADIATION AND CONVECTION TO THE WALL, CONDUCTION THROUGH THE WALL, AND RADIATION AND CONVECTION OUTSIDE THE WALL.

FIG. 268. HEAT TRANSFER IN A STEAM BOILER. (Courtesy, Johns-Manville.)

2. To measure the ability of common substances to insulate heat energy.

Tools and Materials:

4 Metal cans (equal size)	Newspaper
4 Thermometers	Camphor gum
1 Piece of asbestos paper	Hot water

Procedure:

Select four cans of equal size. Polish one until it is bright and shiny. Cover one with soot by smoking it in the flame of burning camphor. Wrap one in asbestos paper. Wrap another can in newspaper until a layer as thick as the asbestos paper is formed.

Pour into each can equal amounts of hot water, nearly filling the cans. Place a thermometer in each can and read the temperature. All should be the same at the beginning. Read the thermometers every two minutes for thirty minutes. Record the results in Table LX.

TEMPERATURE				
Read-ings	*Bright can*	*Black can*	*Asbestos covered can*	*Paper covered can*
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

TABLE LX

Which can loses heat most rapidly? ....

Which the least rapidly? .... On a piece of cross-section paper, plot the fall of temperature for each can against the time. Start each curve at the same point.
Put all four curves on one graph. Study these cooling curves and compare the loss of each can by radiation.

Questions:

1. Heat may be transferred through space by ....

   Molecules that are heated give off .... waves. These

   waves are (visible, invisible) ....

2. Bodies which are .... and .... are the best radiators. Bodies which are hard and bright are good (radiators,

   insulators) .... but poor .... Substances

   which are light and porous are poor ....

3. The radiator of a ear is made with great surface area so that ....

   ....

   Heat is lost from the .... of a radial engine by ....

   A steam boiler is covered with asbestos to prevent ....

4. Radiation of heat is desirable in the following cases:

1) .... 2) ....

3) ....

Radiation of heat is not desirable in the following cases:

1) .... 2) ....

3) ....

New Words:

CONDUCTION.—To transfer heat from one point to another by molecular contact.
CONVECTION.—To transfer heat by flowing or circulation.
FINS.—Flat projections of metal at right angles to a cylinder wall.
INSULATION.—Material that is a poor conductor of heat.
RADIATION.—To move away from, or to be transferred, by vibrant energy.
RADIATOR.—A surface made especially for radiation of heat from a liquid or gas.
RADIAL.—Spreading out from the center as the spokes of a wheel.
VIBRANT.—Quivering or vibrating.

Additional New Words:

__________________ ....

....

__________________ ....

....

__________________ ....

....

CHEMISTRY OF COMBUSTION

FUELS FURNISH ENERGY FOR MACHINES

REFERENCES

Biddle and Bush: *Dynamic Chemistry,* pages 35-69; 597-625.
Dull: *Modern Chemistry,* pages 40-81; 282-341; 679-695.
Hopkins: *Chemistry and You,* pages 23-111; 424-490.
MacPherson-Henderson: *Chemistry at Work,* pages 78-111; 427-451.
TM 10-550 *Fuels and Carburetion,* Entire.
Pamphlets — *Oil,* American Petroleum Institute.

THE CHEMISTRY OF COMBUSTION

Chemistry deals with the changing of raw materials into usable products. Thus crude petroleum, coal, iron ore, clay and limestone are changed into such usable substances as gasoline, lubricating oil, paraffin, aspirin, dyes, iron, aluminum, cement, carborundum, etc. Heat needed for the operation of many types of machines is furnished by the combustion (oxidation or burning) of some type of fuel. Fuels, like all other types of raw materials, are composed of *elements.* There are 92 different elements which make up the earth, air and sea. Only about one third of these are familiar to the average person because most elements are found in nature mixed or combined with other elements.

Elements are grouped as *metallic* and *non-metallic.* Common metallic

elements are iron, aluminum, copper, zinc and lead, while carbon, hydrogen, neon and sulfur are important non-metallic elements. The smallest particle of an element is an *atom*. Atoms of metals (hydrogen is an exception) unite with atoms of non-metals to form molecules of compounds. In previous discussions it has been explained that atoms are composed of small electrical particles of matter, the *electron* and *proton*. The electron is negatively charged and the proton positively charged.

Two types of changes are encountered in working with materials. These are classed as "chemical" and "physical." When the composition of the material is unaffected by the change, the change is physical. The breaking of glass, shaping of metal, sawing of wood and tearing of paper are typical examples of physical change. When the composition of the materials is changed, the change is chemical. When two or more elements combine chemically, molecules of a compound are formed. Many chemical changes result in the decomposition of molecules.

When a fuel burns, it combines with oxygen from the air, and combustion occurs, accompanied by heat and light. In this type of chemical change, electrons are loaned and borrowed by atoms. Since hydrogen gas is a constituent of of most fuels the following example will illustrate the mechanics of such a chemical change.

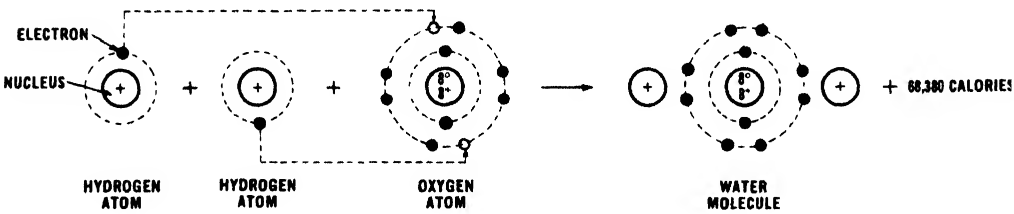


FIG. 269. CHART SHOWING CHEMICAL FORMATION OF H_2O.

In Fig. 269 it is shown that two atoms of hydrogen are required to combine with one atom of oxygen and that a molecule of water is formed. This chemical change is accompanied by the release of 68,380 calories of heat energy. When a fuel is burned to operate a machine, it is this heat energy that is harnessed and converted into mechanical power, however provision must be made for disposing of the products of combustion, such as water, carbon dioxide, carbon monoxide, etc. The simple way to write the equation for the burning of hydrogen is by the use of chemical symbols. The diagram in Fig. 269 then becomes —

$$2H + O \longrightarrow H_2O + 68{,}380 \text{ calories}$$

(2 atoms of hydrogen) + (1 atom of oxygen) gives (one molecule of water vapor)

For further information on the writing of chemical equations the student is referred to texts on the subject of chemistry.

Very few pure substances are found in nature, most materials being *mixtures*. Mixtures differ from compounds in that no chemical change occurs when they are formed. For example, a mixture of air and gasoline vapor is compressed in the cylinder of an internal combustion engine.

These are combined chemically when the spark jumps the gap in the spark plug, the heat energy released by the chemical change expanding the gases in the cylinder, causing the power stroke. The products of combustion, water and carbon monoxide (or carbon dioxide), being released through the exhaust valves and exhaust pipe.

EXPERIMENTING WITH PHYSICAL AND CHEMICAL CHANGES

Purpose:

1. To distinguish between elements, compounds and mixtures.
2. To learn the difference between physical and chemical change.

Tools and Materials:

Iron filings	Test tubes
Powdered sulfur	Bunsen burner
Magnet	Rubber stopper
Chalk	Glass and rubber tubing
Hydrochloric acid	

Procedure:

a) Elements and mixtures

Iron and sulfur are two common elements. Examine them for appearance, color, weight and any other properties which are outstanding. Test their magnetic properties with a permanent magnet.
List the properties of:

Iron ....

Sulphur ....

Mix on a sheet of paper, a small quantity of fine iron filings with an equal quantity of powdered sulfur. Try separating the iron from the sulfur with a magnet.
What is the appearance of the mixture? ....

....

Can each of the two elements still be identified by their original properties? ....

Can they be separated with a magnet? ....

b) Compounds

Place the mixture of iron and sulfur in a test tube and heat it in the bunsen flame until it begins to glow, then remove from the flame and observe what happens.
The mixture (did, did not) .... continue to glow after it was removed from the flame.

Note whether or not some of the sulfur burns with a blue flame, or whether there seems to be more sulfur than the iron can combine with.

Observation ....

Break the test tube and examine the product. Now try to separate the two elements with a magnet. The material is now a compound, iron sulfide.

What are its properties? ....

Can you still identify the two elements by their original properties? ....

.... Can they be separated by a magnet? ....
What do you think the differences are between mixtures and compounds?

....

Between physical and chemical changes? ....

....

Grind up a piece of chalk into a fine powder. What type of a change has occurred? .... In a test tube, place a few drops of dilute hydrochloric acid on the powdered chalk. What happens? ....

....

Fit the test tube with a stopper and rubber delivery tube as shown in

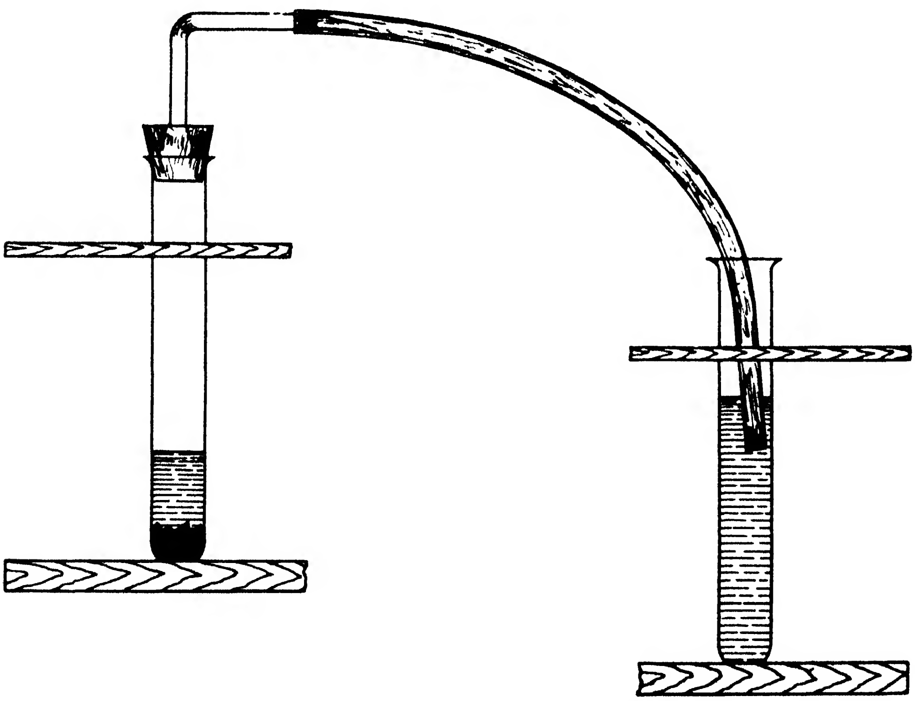


FIG. 270. TEST TUBE AND DELIVERY TUBE.

Fig. 270. Place the end of the rubber tube into another test tube half filled with lime water. Remove the stopper, add a few more drops of acid to the chalk, quickly replace the stopper and observe what happens to the lime water. The lime water becomes .... due to

....

....

The gas being released from the chalk is carbon dioxide (CO_2). It caused the lime water to turn milky because it formed insoluble chalk ($CaCO_3$) again. This is a simple test by which a gas can be identified as CO_2.

FUELS

Fuels are substances which, when burned, produce heat and light. Many fuels are *organic* compounds, being composed mostly of carbon and hydrogen. These elements may be present in the free state or combined as *hydrocarbons.* A few fuels contain other elements in combination with the carbon and hydrogen which add little or nothing to their heat producing value. Substances which burn with a flame are gaseous or capable of becoming gaseous when heated. Solid fuels, such as coke or charcoal, burn with a glow only, producing no flame.

The important solid fuels are coal, coke, wood and charcoal. Natural gas, consisting mostly of methane, is an important fuel in many sections of the country, while artificial or manufactured gases, such as producer gas, coal gas and acetylene have many important industrial uses. Petroleum (crude oil) is the source of most liquid fuels. Alcohol and benzol (from coal) have limited use as fuels.

COMBUSTION

Purpose:

1. To study the conditions necessary for combustion.
2. To determine the products of complete and incomplete combustion.

Tools and Materials:

Candle
Wide mouth bottle or jar
Quicklime
Charcoal
Bunsen burner
Ringstand and ring
Paper cup
Wire gauge
Jet tube
Calcium chloride drying tube
Dilute sulfuric acid
Potassium chlorate
Manganese dioxide
Test tube
Two small wide mouth bottles
Rubber delivery tube
Pneumatic trough
Combustion spoon
Lime water
Thistle tube
Mossy zinc

Introduction:

Before combustion can take place, three conditions must be present, namely, 1) a supporter of combustion, 2) a combustible substance, and 3) the proper temperature (kindling temperature).

The products of combustion depend upon the chemical composition of the fuel and the completeness of combustion. Complete combustion is controlled by the amount of oxygen present and the uniformity with which it is mixed with the fuel. Insufficient air (or oxygen) results in incomplete burning; this in turn, results in the loss of heat due to the escape of combustible gases. Carbon monoxide (CO), a dangerously poison gas, and carbon (soot) are two of the most common products of incomplete combustion.

Procedure:

a) Conditions necessary for combustion

1) Combustion supporter

Invert a wide mouthed bottle or jar over a burning candle, Fig. 271 and observe the behavior of the flame.

2) Combustible substance.

Place a lump of quicklime (CaO) and a piece of wood charcoal on a wire screen supported on the ring of a ring stand. Heat both intensely with the flame from a bunsen burner. Observe any change that occurs in each substance.

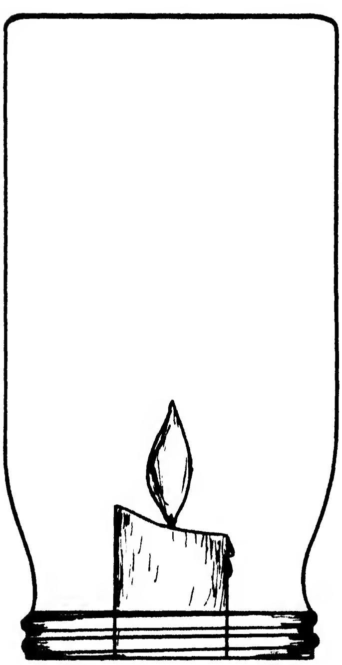


FIG. 271. BOTTLE OVER A CANDLE.

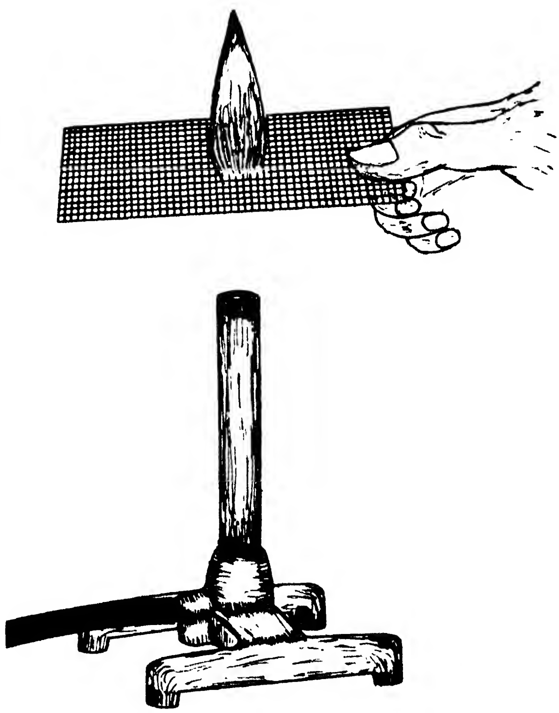


FIG. 272. WIRE GAUZE OVER BURNER.

3) Combustion temperature

Lower a heavy wire gauze horizontally into the flame of a bunsen burner. See Fig. 272. Observe the position of the flame. Blow out the flame, hold the wire gauze about 2 inches above the top of the burner and place a lighted match in the gas above the screen. Note the position of the flame.

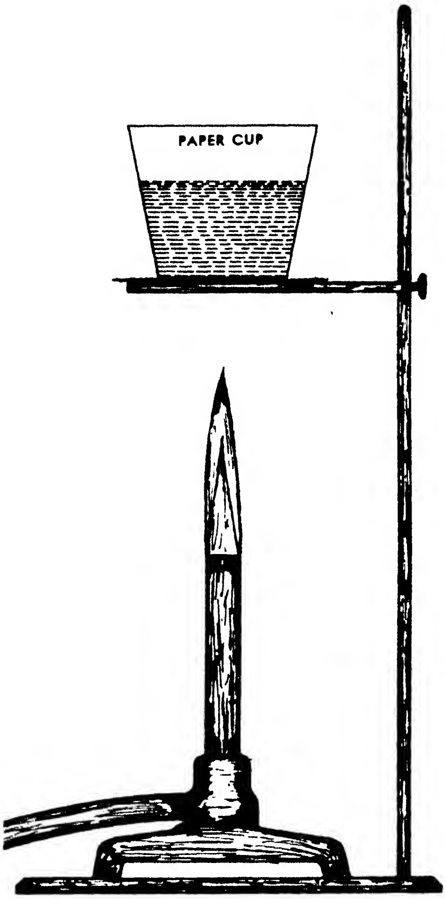


FIG. 273. PAPER CUP OVER BURNER.

Fill a paper drinking cup half full of water and place it on a wire gauze over a bunsen flame. See Fig. 273. Heat until the water boils, watching the behavior of the paper cup.

Questions:

1. The candle (continued to burn, ceased to burn, burned more brightly) .... when placed under the inverted bottle because ....
2. The (quicklime, charcoal) .... burned when heated in the bunsen flame showing that .... is a combustible substance and .... is not.
3. The gas flame (does, does not) ....pass through a wire screen because ....

   This is the principle upon which the miner's safety lamp, invented by Davy, operates.
4. When water is boiled in a paper cup, the cup (did, did not) ....burn below the water level because ....

b) Products of combustion

The three most important elements used during combustion are Oxygen, Carbon and Hydrogen.

A) Oxygen

Prepare and collect two bottles of oxygen gas as follows. Mix 10 g. of powdered potassium chlorate ($KClO_3$) with 3 g. of powdered manganese dioxide (MnO_2) thoroughly on a piece of paper. When mixed, pour it carefully into a dry test tube, fit the tube with a one-hole rubber stopper and set up the remainder of the apparatus as shown in Fig. 274. Fill two wide

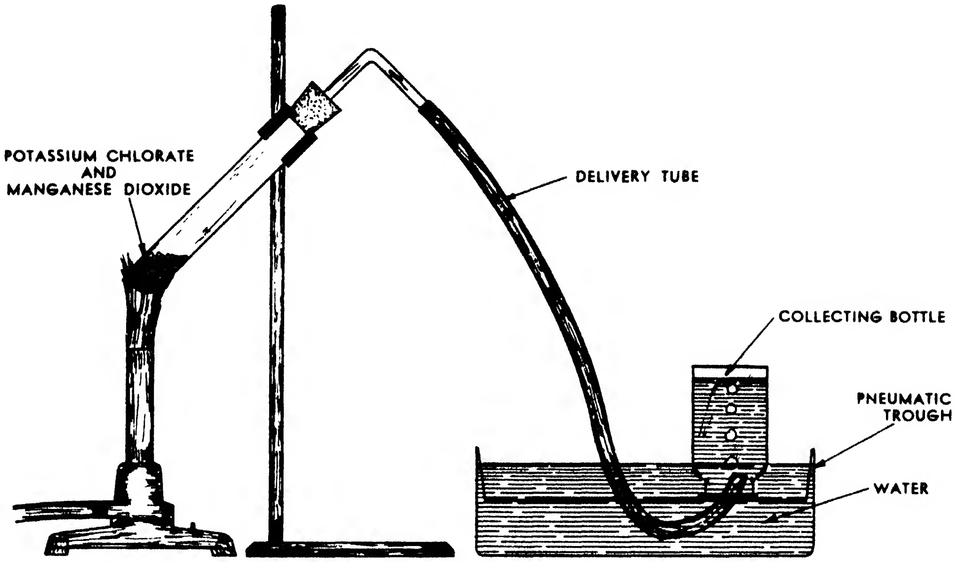


FIG. 274. PREPARATION OF OXYGEN.

mouth bottles with water, cover them with a glass plate, and invert them in the tank (pneumatic trough) of water. When the mouth of the bottle is under water, remove the glass plates.

Now heat the test tube gently with a small flame, allowing the gas bubbles to escape from the rubber delivery tube for about a minute. Why? Fill the two bottles with oxygen gas by placing the rubber delivery tube under the mouth of the inverted bottle. When the water has all been forced out of the bottle, close the mouth of the bottle with a glass plate and set the bottle upright on the table for later use.

Tests:

Place a glowing pine splint quickly into one of the bottles of oxygen.

What happens? ....

Is oxygen a good supporter of combustion? ....

Heat a small piece of charcoal, held on a combustion spoon, in a flame until it glows. Place the glowing charcoal in the second bottle of oxygen (see Fig. 275) covering the bottle as much as possible with a glass plate.

Describe your observations ....

....

....

When the action has finished, pour about 10 ml. of limewater into the wide mouth bottle, cover the mouth of the bottle and shake. What happens

to the limewater? ....

This proves the formation of what gas when carbon is burned? ....

B) Hydrogen (Caution — A mixture of hydrogen and air is explosive)

Set up a hydrogen generator as shown in Fig. 276. Place a few pieces

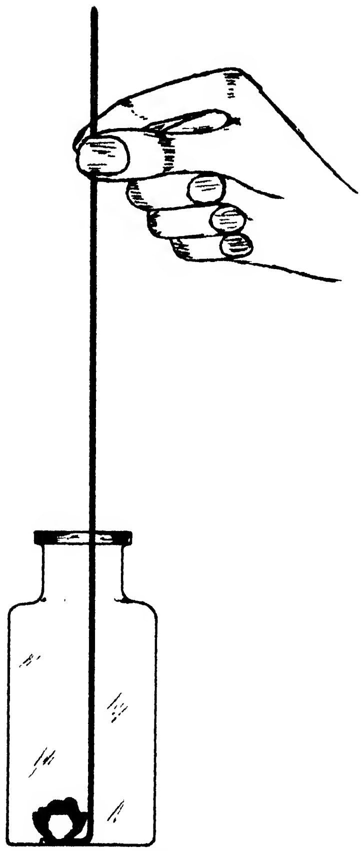


FIG. 275. CHARCOAL IN BOTTLE OF OXYGEN.

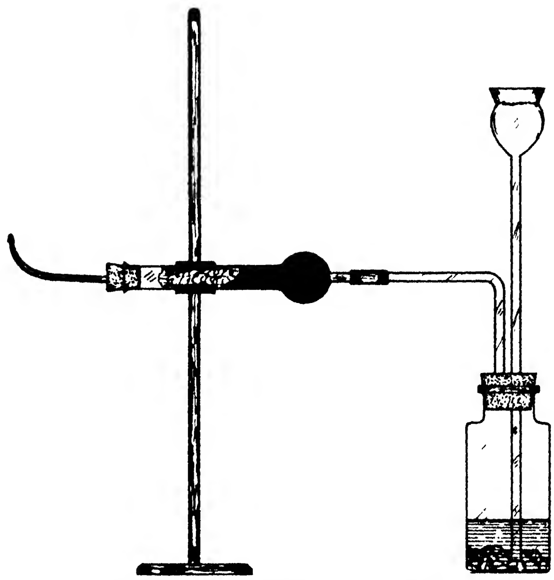


FIG. 276. HYDROGEN BURNING.

of mossy zinc in the bottle and pour 25 ml. of dilute sulfuric acid through the thistle tube. If the gas does not generate very rapidly, add a few ml. of copper sulfate solution. Allow the gas to leave the generator for *two minutes,* (not less), then hold a cold, dry bottle over the jet tube. Do you notice anything happen? ....

Now light the hydrogen gas coming from the jet tube and hold the bottle over the burning gas. What do you see condensing on the inside of the bottle? ....

This proves that .... is formed when the hydrogen in a fuel is burned.

Note: About .83 gallon of water is formed for every gallon of gasoline that is burned in a gasoline engine. Some of this water can be seen dripping out of the exhaust pipe of an automobile on a cold morning.

EXPLOSIVE MIXTURES

An explosion is caused by a sudden change in volume. This is brought about by changing a liquid or solid to the gaseous state during chemical action, and by expansion due to the heat of the reaction. An explosion may also be caused by instantaneous combustion. When combustible particles are small, they may come in contact with a large amount of oxygen.

Under such conditions, if the temperature is raised above the kindling point, by a spark for example, ignition may occur instantly. Dust explosions, and the explosion of gasoline vapors in the cylinder of an automobile are examples of this.

Liquid gasoline is not explosive. The carbureter of an engine is a device for mixing gasoline vapor with air in just the right proportion to give the most powerful explosion possible. When the engine is cold, the gasoline does not evaporate fast enough and the mixture is "to lean" to explode readily. When the "choke" is pulled, some of the air supply is shut off and the mixture becomes "richer." If the choke is closed too long, the cylinders become "flooded" with liquid gasoline, not enough air being present to form an explosive mixture.

It was learned in a previous section that elements combine in definite amounts during a chemical change. In any mixture of gas and air, the explosion is most powerful when the gases are mixed in the ratio of their combining volumes. Acetylene will explode if the mixture contains from 3% to 30% acetylene gas. This is known as the explosive range. The explosive range of hydrogen is from 10% to 66% hydrogen, but the most violent mixture contains 29% hydrogen.

THE BUNSEN BURNER

Examine the construction of a bunsen burner and compare it with the diagrams in Fig. 277. Light the burner, adjusting the flame to burn about 3 inches high. Turn the ring (or slide) at the base of the barrel so as to

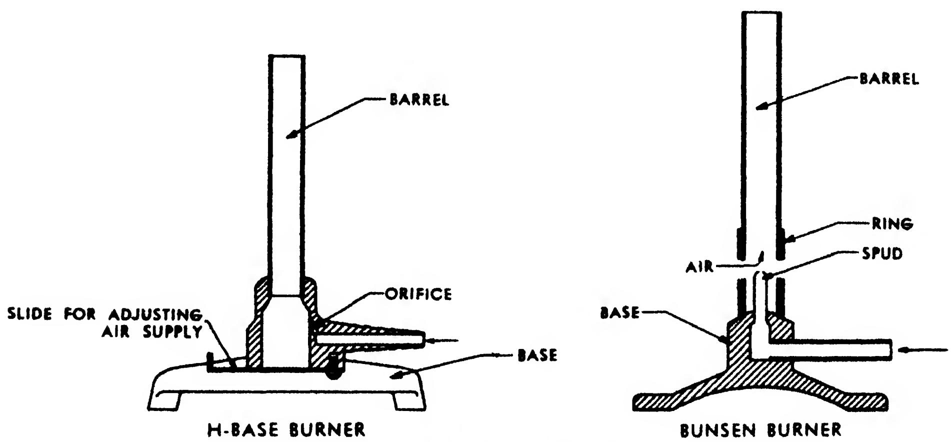


FIG. 277. BUNSEN BURNERS.

close the air holes. Observe the change in the flame. The air entering the holes at the base is known as *primary air*, while that combining with the gas as it leaves the barrel is spoken of as *secondary air*. With the primary air shut out, hold a glass stirring rod in the flame a short while and notice any deposit that forms on it.

Open the holes at the base of the barrel and observe any change in the flame. Hold the stirring rod (with the carbon deposit still on it) in this flame. Observe any change in the deposit on the rod. Adjust the burner to produce a blue flame. Observe the two distinct cones in the flame. Hold

a strip of copper in the tip of the outer cone and observe its color change. Now bring the copper strip slowly down into the tip of the outer cone. Observe the color change. The copper is oxidized in the outer cone and reduced in the inner cone.

Place a piece of cardboard vertically in a small, blue, bunsen flame (See Fig. 278) long enough to scorch it. Remove it from the flame before it catches fire. Observe where the heat is concentrated in the flame.

Questions:

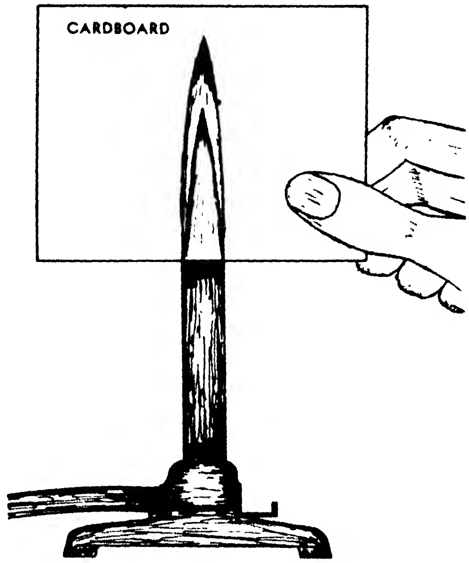


FIG. 278. CARDBOARD OVER BURNER.

1. The flame burns (yellow, blue) .... when the holes at the base of the barrel are closed. This flame deposits .... on a cold object showing that its color is produced by ....
2. The copper strip changed to a .... color when held at the tip of the outer cone because it was (oxidized, reduced) .... and .... when lowered into the tip of the inner cone because ....
3. The scorched cardboard shows that the flame is hottest at ....

PETROLEUM

Gasoline and lubricating oil are obtained by refining petroleum. Petroleum is a liquid mineral. The name is derived from the Latin words *petro*, rock, and *oleum*, oil. The petroleum of commerce is commonly known as crude oil. Crude oil is a complex mixture of hydrocarbons. Oils from different fields vary widely in their properties. Some are thick like tar, some heavy like molasses, others light and volatile. The color may be black, or shades of yellow, brown or green. Fig. 279 shows how oil deposits may be found or missed by the driller. This cross-section through part of the

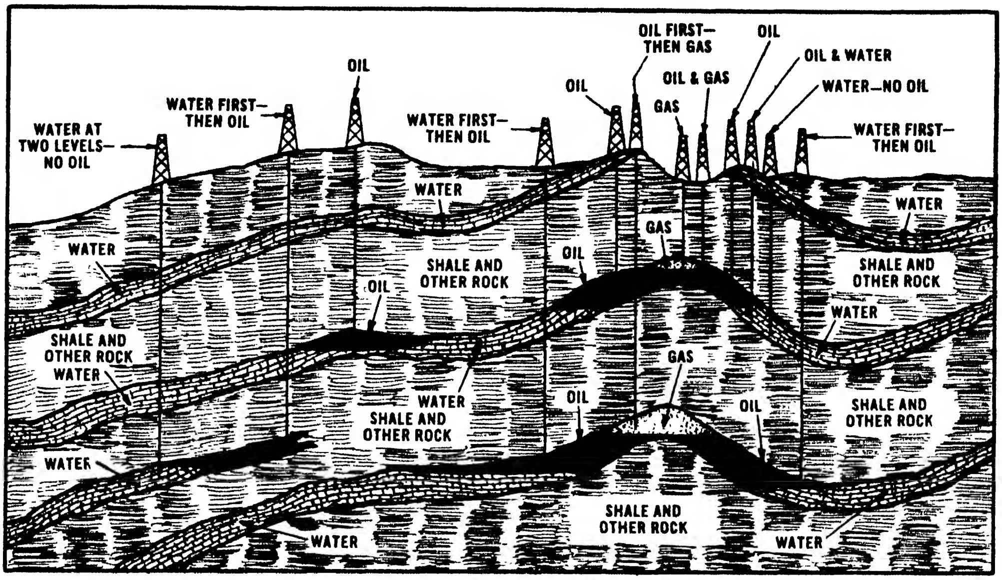


FIG. 279. OIL STRATA.

earth's crust shows how oil tends to collect in porous rock formations underground. Being lighter than water, the oil (often with some natural gas) is forced upward along the porous strata until it is caught in a pocket and can move no farther. Observe how the drill may encounter oil at several producing levels or may strike nothing but water, even though close to an oil-producing well.

Scientific drilling methods have greatly reduced the number of "dry holes" but the result is always in doubt until oil is actually found.

Some wells come in under terrific natural gas pressure. Many continue to produce, by pumping, years after the initial pressure is exhausted.

In normal times as many as 25,000 wells may be drilled in the United States annually.

REFINING

In Fig. 280 is a general view of a modern refinery showing the fractionating towers, absorbers and gas purififcation system. Crude petroleum is composed of a mixture of hydrocarbon molecules of different weights or volatilities. "Straight run" refining consists of heating this molecular mixture to the point where it gives off vapors just as boiling water gives off steam. The lightest molecules vaporize first and when the vapor is passed through cooled pipes it condenses to form gasoline. As the temperature is raised by stages, the other, heavier hydrocarbon molecules are vaporized in the order of their volatility, and condensed by cooling, to form other products: —kerosene, gas-oil, lubricating oil and fuel oil. This process of distillation is known as "fractional distillation."

DISTILLING PETROLEUM

Purpose:

To separate crude oil into gasoline, kerosene and fuel oil by fractional distillation

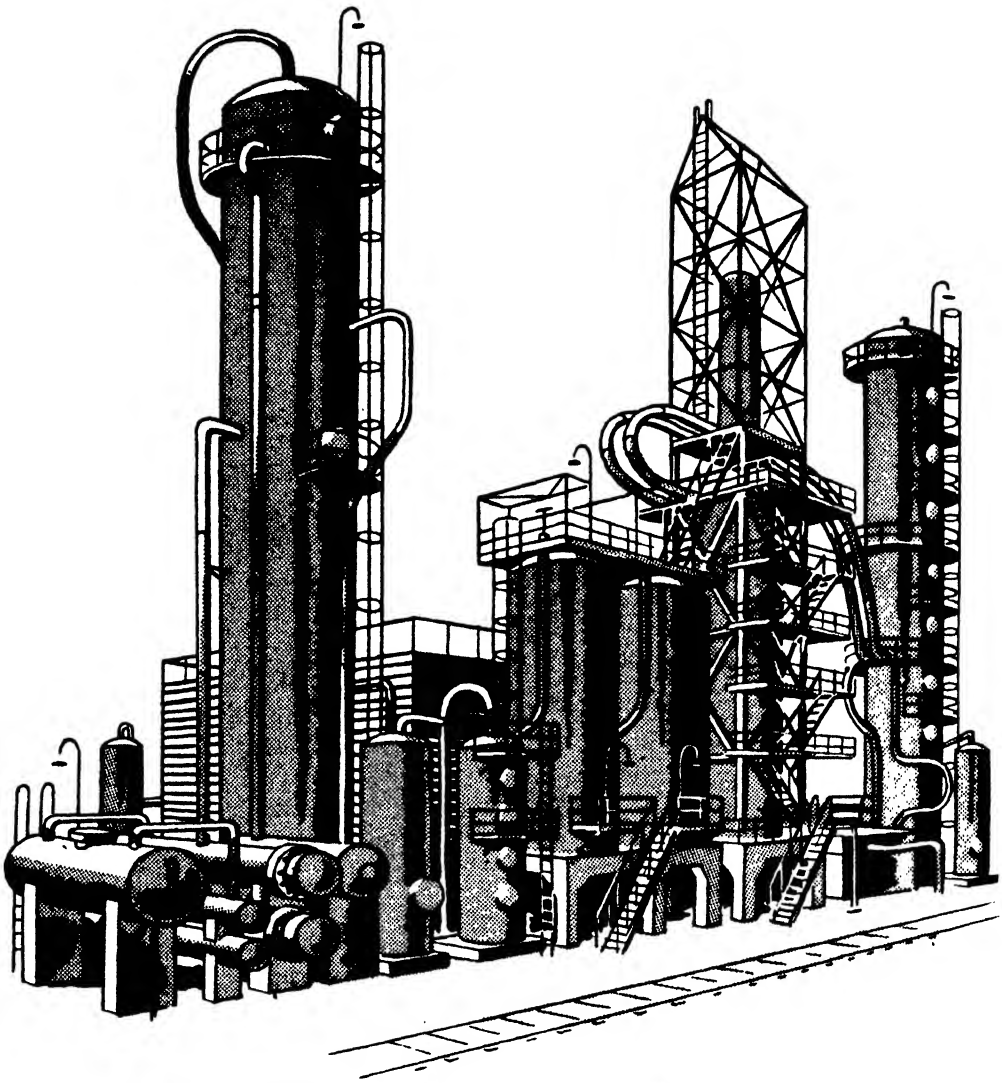


FIG. 280. A MODERN OIL REFINERY. (Courtesy, Blaw-Knox Company.)

Tools and Materials:

Florence flask
Liebig condenser
Thermometer (700°F)
Electric hot plate
(or bunsen burner
and sand bath)

Procedure:

Caution: Since crude oil and its products are inflammable, extreme care should be taken in heating with an open flame. It is suggested that the flask containing crude oil be heated in a pan of sand. An electric hot plate is to be preferred as the source of heat.

Set up the distilling apparatus as shown in Fig. 281. Fill the flask about one-half full of crude oil and heat slowly until the temperature reaches 350°F, collecting the distillate in a clean, dry test tube. This is the gasoline fraction. Continue heating until the temperature reaches 475° F, collecting the distillate in a second test tube. This distillate is kerosene.

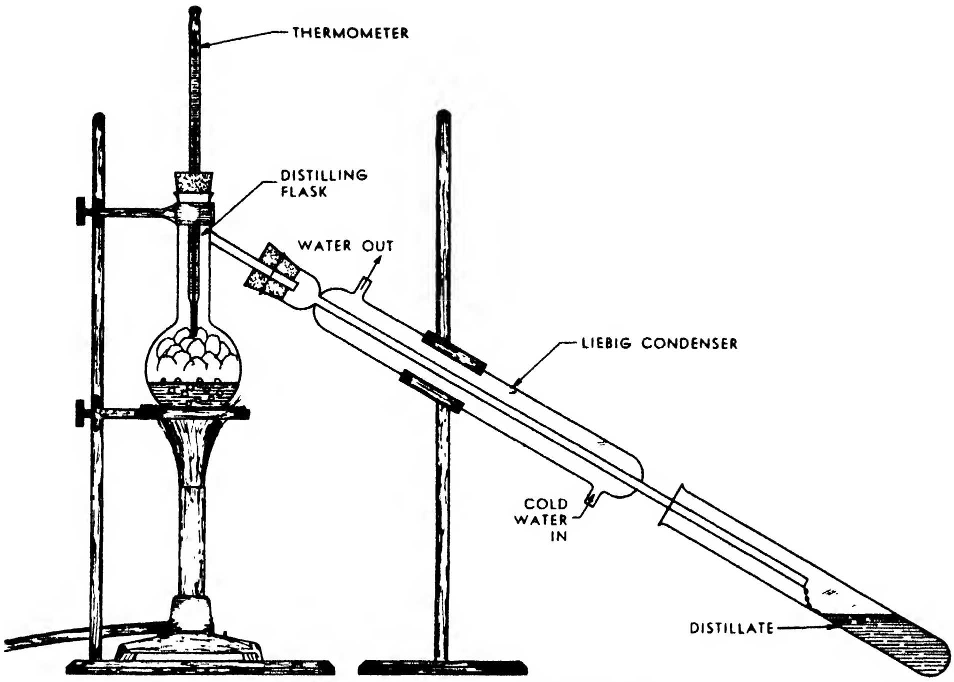


FIG. 281. DISTILLING APPARATUS.

Heat until the temperature reaches 675°F, collecting the distillate in a third test tube. This material is fuel oil.

Questions:

1. Why is this process called "fractional distillation"? ....

   ....
2. If the crude oil used was an asphalt base oil, what would remain in the distilling flask when all the volatile materials have been driven off? ....

   ....
3. (Asphalt, coke) .... is the substance remaining in the distilling flask or still when a paraffin base crude oil is distilled.
4. Name some other products obtained from crude oil. ....

   ....

OTHER REFINING PROCESSES

Crude oil contains sulfur, but this sulfur is not present in the usual yellow powdered form, but as intricate compounds invisible to the eye. Sulfur compounds have objectionable odors and form corrosive acids and therefore must be removed from the refined products. There are various methods of removing sulfur from gasoline and kerosene. A common method is to thoroughly mix concentrated sulfuric acid with the gasoline or other product. The impurities formed by the chemical reaction are allowed to settle, then are removed. Any acid that may be left, is neutralized

with caustic soda (sodium hydroxide). Finally the gasoline is washed with water to remove the caustic solution.

CRACKING

About 1915, with the demand for motor fuel rapidly increasing, petroleum refiners began to supplement straight run refining by "cracking." Cracking consists of subjecting the heavier constituents (the gas-oil and fuel-oil) of crude oil, obtained by straight run refining, to high pressures and temperatures which split the heavy molecules into lighter ones, much like a stone is crushed by a hammer. Gasoline and other products are then separated from the cracked oil by a process similar to straight run refining. Cracking has practically doubled the amount of gasoline obtainable from a 42 gallon barrel of crude oil. The amount of crude oil saved by the cracking process represents approximately 65% of our currently estimated reserves.

CATALYTIC CRACKING

Catalysts are substances which cause chemical reactions to occur without having their own composition changed. Recently several processes for "cracking" petroleum by the use of catalysts have been perfected. These processes are of great importance because they eliminate the high pressures and temperatures formerly needed, saving large quantities of steel and other vital war metals; they also make possible more accurate control of the refining processes and have resulted in the production of exceedingly high octane gasoline, explosives and raw materials for producing synthetic rubber.

Three processes are now being used which permit continuous catalytic cracking. The first is known as the Houdry process, named from its originator, the French engineer, Eugene Houdry. The second is the Thermofor Catalytic Cracking (TCC) process and the third, the Synthetic Bead Catalyst. This latter process makes possible the production in commercial quantities, gasoline that can produce 35% more power than any previous 100 octane gasoline.

POLYMERIZATION

A recently developed refining process known as polymerization makes it possible to produce gasoline from gases generated during the cracking process, and formerly wasted or used for refining fuel. Briefly, polymerization is almost the reverse of cracking. Instead of splitting heavy molecules into lighter ones, polymerization takes the light gas molecules and synthesizes them to create heavier, more complex molecules of gasoline. This still further increases the amount of motor fuel obtainable from a barrel of crude oil.

OCTANE RATING

The ability of a gasoline to resist detonation (knocking) is called its octane or antiknock rating. A straight run gasoline from asphaltic base crudes has better antiknock value than one from paraffinic base crudes. Cracked gasoline generally has less tendency to knock than straight run gasoline. All marketed gasolines are a blend of straight run and cracked gasolines, so unless their blending is controlled, their antiknock qualities will vary.

Engineers and refiners have devised a method of determining and comparing the antiknock qualities of gasolines by using a special one-cylinder engine, known as the C.F.R. (Cooperative Fuel Research Committee) fuel testing engine, in which the compression pressure can be raised or lowered. A device records and measures the knocking effect of the fuel being tested. A mixture of iso-octane, which has a very high antiknock rating, and heptane, which produces a pronounced knock, is used as a reference fuel to establish an antiknock standard. The antiknock value or octane number of a gasoline being tested is represented by the percentage by volume of iso-octane that must be mixed with normal heptane in order to duplicate the knocking of the gasoline being tested. Octane numbers range from 50 in third-grade gasolines to over 100 in aviation gasolines. Since an octane number of 100 indicates a fuel having an antiknock value equal to that of iso-octane, a number higher than 100 indicates that the antiknock value is that much greater than that of iso-octane. Fuels now being refined by the new continuous catalytic process, are so powerful they cannot be given an octane rating.

If the octane rating of a gasoline is naturally low, the fuel will detonate as it burns and power will be applied to the pistons in hammer-like blows. The ideal power is that which pushes steadily rather than hammers against the pistons. The octane rating of a gasoline can be raised in two ways; by mixing it with another fuel, or by treating it with a chemical such as tetra-ethyl lead.

1. By the first method, gasoline is mixed with benzol or alcohol. It takes from 30 to 40 percent of benzol to get a good antiknock rating and an even greater percentage of alcohol. Alcohol absorbs moisture from the air and the water formed has a tendency to collect in the fuel system. Neither alcohol nor benzol have the ability to produce as much heat as gasoline, so a richer mixture is necessary to give good combustion when this blend of fuels is used. In this country, no fuel mixed with alcohol is sold. However, some fuel mixed with benzol is sold, especially in territories which are close to coke ovens, the principal source of benzol.

2. A treated fuel is one which contains a chemical that is not a fuel. Iodine is effective but it is detrimental to the metal of the engine. The most satisfactory chemical known is tetra-ethyl lead compound, which is added to gasoline in the proportion of about 1 to 1,200 by volume, depending on the fuel and the antiknock value desired. The chemical commonly used contains tetra-ethyl lead (produced from alcohol and lead), ethylene dibromide, ethylene dichloride, and aniline dye. Tetra-ethyl lead is a liquid which mixes thoroughly with gasoline and vaporizes completely. Ethylene dibromide prevents the tetra-ethyl lead from forming lead oxide deposits on spark plugs and on valve seats and stems. Dye is added to identify an ethyl treated gasoline and to warn against its being used as anything but an engine fuel. Ethylene dichloride assists the ethylene dibromide in eliminating deposits.

An engine which does not knock on a low octane fuel does not increase in efficiency when operated on fuel with a higher octane rating. If the knock does not stop, some mechanical adjustments are probably necessary.

Adjusting the spark of an engine using a low antiknock gasoline so that it will fire later (retarding the spark), eliminates knocking, but fuel consumption will be increased and the engine will overheat. It may be less expensive to use a higher priced, high octane gasoline with an advanced spark than to use a cheap, low octane gasoline with a retarded spark.

HYDROGENATION

Coal can be hydrogenated at very high pressures and temperature to produce a synthetic crude oil from which gasoline can be obtained. Today's high-compression engines and other essential parts of modern machines are completely dependent upon the improved motor fuels and lubricants which research has enabled the oil industries to produce in their refineries.

New Words:

DISTILLATE.—The liquid which condenses during the process of distillation.

FRACTIONAL DISTILLATION.—The process of separating a mixture of liquids having different boiling points.

HEPTANE.—A hydrocarbon containing seven carbon atoms (C_7H_{16}).

HYDROGENATION.—The chemical process of combining hydrogen with another substance.

HYDROCARBON.—A chemical compound composed of carbon and hydrogen.

KINDLING TEMPERATURE.—The lowest temperature at which a compound or element will burn.

NEUTRALIZE.—The interaction of an acid and base (alkali) to produce a salt and water.

OCTANE.—A hydrocarbon containing eight carbon atoms (C_8H_{18}).

ORGANIC.—Any chemical compound containing carbon.

POLYMERIZATION.—The process of building large molecules by combining several smaller molecules.

SYNTHESIZE.—To build a molecule of a substance from atoms or smaller molecules.

Additional New Words:

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....

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INDEX

Absolute, temperature, 199; units, 37; zero, 199
Acceleration, defined, 238; laws of,238
Adhesion, 154
Air cleaner, oil wetted type, 155; centifrugal 254; crankcase, 157 filtering element, 156; louvre type, 157; oil bath type, 157
Airplane, wing, 233; engine, 283
Air thermometer, 291
Antifreeze, 190

Babbitt metal, 70
Balances, use of, 24
Barometer, 198
Bearings, antifriction, 66; friction 69; bronze, 71; silver surfaced, 71
Belts, types of, 49
Bending factor, 164
Bernoulli's principle, 214
Block and tackle, 94
Boiling point, 273
Bourdon gage, 198
Boyle's Law, 196
Brownian movement, 152
Bunsen burner, 33

Calorimeter, 264
Çam, 106
Capillary action, 177
Carbureter, 216
Centigrade scale, 262
Centrifugal, clutch, 252; pump, 251; spark advance, 253
Centripetal force, 250
Change, chemical, 296; physical, 296
Charles' Law, 197
Cohesion, 153
Combustion, 294, 298
Compound bar, 266
Compression ratio, 207
Compressor, rotary, 281; reciprocating, 282
Conduction, 283
Convection, 288
Cooling system, 289
Couple, 219
Coupon testing, 166
Crane, portable, 134
Curve, epicycloid, 118; cycloid, 117; hypocycloid, 118; involute, 117

Density, 23
Derrick, 226
Die, for drawing wire, 14
Differential gears, 126
Distillation, fractional, 305
Ductility, 14

Efficiency, of machines, 61, 79
Elasticity, 158
Elastic limit, 159
Electron, 295
Element, 294
Emulsions, 186
Energy, 35, 61
Engines, Diesel, 205; four stroke cycle, 209; gasoline, 205; internal combustion, 200; two stroke cycle, 211
Equilibrium, 85
Equilibrant, 219
Evaporation, 272
Expansion, coefficient of, 265

Factor of safety, 158
Fahrenheit scale, 262
Files, 111
Filtration, 189
Fire point, 184
Flame, 298
Flash point, 184
Foot pound, 37
Foot poundal, 41
Force, 37, 218
Forces, centrifugal, 249; centripetal, 250; compositlon of, 221; parallel, 233, resolution of, 223
Frame, automobile, 232
Friction, coefficient of, 71; kinetic, 71; laws of, 65; static, 71
Fuels, 294, 298
Fuel injector, 202

Gas refrigerator, 277
Gears, bevel, 126; cycloid, 117; helical, 125; herringbone, 125; hypoid, 126; idler, 128; involute, 117; internal, 121, 122; miter, 126; notation, 120; pinion, 119; ratios, 138; size of teeth, 124; spur, 120; terms, 120; worm, 127
Gearing, back, 137; compound, 128; lathe, 136; simple, 127
Governor, 252
Grade, 105
Gravity, center of, 84, 88
Grease, 193

Hacksaw, 114
Hardness, 16
Heat, 256; measurement of, 263; specific, 268; transfer, 283
Heat of condensation, 274; of fusion, 271; of vaporization, 274
Helix, 124
Hookes Law, 159
Horsepower, 42
Houdry process, 308
Humidity, 272
Hydraulics, 141
Hydraulic, brake, 147; clutch, 149; jack, 143; press, 142
Hydrogenation, 309
Hydrometer, 192

Inclined plane, 104, 107; grade of, 105
Immiscible liquids, 188
Impenetrability, 11
Inertia, 11; 240; rotary, 242
Input, 61
Insulation, 286

Kilogram, 23
Kilometer, 20
Kinetic theory, 152

Lever, classes of, 76, 79; examples of, 82; law of, 78; mechanical advantage of, 77
Lift, 216
Liquid air, 266
Locomotive, 287
Lubrication, 178
Lubricating system, 181

Machines, 34, 60; law of, 62
Malleability, 10
Mass, 10
Matter, definition, 9; states of, 9
Mechanical advantage, 61
Mechanical efficiency, 44
Melting point, 270
Meniscus, 22
Metric - English equivalents, 23
Metric system, 19
Micrometer calipers, 26
Mixtures, 295; explosive, 302
Moh's scale, 16
Molecular motion, 152
Moments, principle of, 78; clockwise, 78, 79; counterclockwise, 78,79
Momentum, 243
Monel metal, 186
Motion, 236; laws of, 240

Nature, of solids, liquids and gases, 9; of solute and solvent, 187

Octane rating, 308
Oil, lubricating, 181, 183, 193; pump, 182; filter, 194; wedge, 178
Otto cycle, 201
Oxygen, 261, 297, 301

Pascal's law, 142
Petroleum, 304; refining of, 305; cracking of, 308
Photomicrograph, 71
Polymerization, 308
Pour point, 179
Power, 42
Prony brake, 43
Proton, 295
Pulleys, 47; systems of, 97; differential, 100, 101, 102
Pycnometer, 192

Rack and pinion gear, 119
Radiometer, 257
Radiation, 290
Refrigerator, gas, 276, 277
Resultant, 219
Rockwell hardness tester, 17
Rock wool, 287
Roof truss, 228

Screw, 105
Screw jack, 106, 109
Shock absorber, 150
Sines, law of, 225
Sludge, 193
Solutions, types of, 186
Solute, 186
Solvent, 186
Spray gun, 215
Specific gravity, 191
Spring, semi-elliptical, 171; coil, 172; shackle, 172
Standard conditions, 9
Stability, kinds of, 85; measure of, 87
Steam engine, 49
Strength factor, 164
Superfinish, 64
Supercharger, 254
Surface tension, 176

Temperature, measurement of, 199, 262
Tenacity, 11
Tensile strength, 169
Thermal conductivity, 284; efficiency, 264
Thickness, chordal, 122; pitch circle, 122
Tire valve, 198
Tire gage, 198
Tools, 111
Torque, 167
Torsion, 166
Trajectory, 246
Transmission, synchromesh, 139
Trusses, 231

Ultimate stress, 159
Ultramicroscope, 152

Valve overlap, 211
Valve insert, 266
Vectors, 219
Velocity ratio, 61
Venturi, 216
Vernier calipers, 30; gear tooth, 123
Viscosity, 173
Viscosity meter, 174

Wedge, 106
Weight, 10, 22
Wheel and axle, 99
Winch, 135
Work, 37, 61

Yield point, 159
Yard, 19

Zero, absolute, 199

I. ENGLISH SYSTEM OF MEASURES

LENGTH

12 inches (in. or ″)	=	1 foot (ft. or ′)
3 feet	=	1 yard (yd.)
$5\frac{1}{2}$ yards or $16\frac{1}{2}$ feet	=	1 rod (rd.)
320 rods or 5280 feet	=	1 mile (mi.)

SQUARE MEASURE

144 square inches (sq. in.)	=	1 square foot (sq. ft.)
9 square feet	=	1 square yard (sq. yd.)
$30\frac{1}{4}$ square yards	=	1 square rod (sq. rd.)
160 square rods	=	1 Acre (A.)

CUBIC MEASURE

1728 cubic inches (cu. in.)	=	1 cubic foot (cu. ft.)
27 cubic feet	=	1 cubic yard (cu. yd.)
128 cubic feet	=	1 cord (cd.)

WEIGHT

16 ounces (oz.)	=	1 pound (lb.)
2000 pounds	=	1 ton (T.)

LIQUID MEASURE

4 gills (gi.)	=	1 pint (pt.)
2 pints	=	1 quart (qt.)
4 quarts	=	1 gallon (gal.)

ANGLES AND ARCS

60 seconds (″)	=	1 minute (′)
60 minutes	=	1 degree (°)
90 degrees	=	1 right angle
360 degrees	=	1 circle

II. CONVERSION TABLES

With Weights and Measures

Inch	=	2.54 cm.
Sq. Inch	=	6.45 sq. cm.
Cu. Inch	=	16.387 cc.
Foot	=	0.3048 meter
Sq. Foot	=	0.0929 sq. meter
Cu. Foot	=	28.316 liters
		7.48 gallons
Cu. Foot Water	=	62.426 lbs.
Yard	=	0.9144 meter
Sq. Yard	=	0.836 sq. meter
Meter	=	39.37 inches
		3.2808 feet
		1.0936 yards
Kilometer	=	0.6214 mile
Mile	=	1.6093 kilometer
Ounce Avoir.	=	28.34954 gms.
		0.02835 kg.
		437.5 grains
		0.911458 oz. ty.
Ounce Troy and Apoth.	=	31.103496 gms.
		0.311 kg.
		1.0971 ozs. av.
		480 grains
Ounce (fluid)	=	29.574 cc.
Pound Avoir.	=	0.453592 kg.
		14.5833 ozs. ty.
		7000 grains
Pound Troy	=	0.373236 kg.
		13.1652 ozs. av.
		5760 grains
Gram	=	15.43235 grains
		0.64301 dwt.
		0.03215 oz. ty.
		0.03527 oz. av.
Kilogram	=	15,432.4 grains
		32.15072 ozs. ty.
		2.6792 lbs. ty.
		35.27394 ozs. av.
		2.20462 lbs. av.
		0.019684 cwt.
1 Ton (Short) (2,000 lbs. av.)	=	907.185301 kgs.
		29,166.66 ozs. ty.
		0.89285 long ton
		0.90718 tonneau
Quart	=	0.9463 liter
Liter	=	1.0567 quart
		0.2642 gallon
Gallon U. S.	=	3.7853 liters
		231.0 cu. inches
Gallon U. S. Water	=	8.337 lbs.

III. METRIC SYSTEM OF MEASURES

10 millimeters (mm.)	=	1 centimeter (cm.)
10 centimeters	=	1 decimeter (dm.)
10 decimeters	=	1 meter (m.)
10 meters	=	1 dekameter (Dm.)
10 dekameters	=	1 hectometer (Hm.)
10 hectometers	=	1 kilometer (Km.)

METRIC-ENGLISH EQUIVALENTS

1 millimeter	=	.03937 inch
1 centimeter	=	.3937 inch
1 decimeter	=	3.9370 inch
1 meter	=	39.37 inch or 3.28 feet
1 inch	=	2.54 centimeters
1 foot	=	30.48 centimeters or .3048 meters
1 yard	=	91.44 centimeters or .9144 meters

METRIC WEIGHTS

10 grams (g.)	=	1 dekagram (Dg.)
10 dekagrams	=	1 hectogram (Hg.)
10 hectograms	=	1 kilogram (Kg.)

METRIC-ENGLISH EQUIVALENTS

1 gram	=	.0353 oz. avoirdupois
1 kilogram	=	2.2 pounds
1 ounce	=	28.35 grams
1 pound	=	.4536 kilograms

CAPACITY

1 liter (l.)	=	1000 cubic centimeters (cc.)
1000 liters	=	1 kiloliter (Kl.)

IV. DECIMAL EQUIVALENTS OF COMMON FRACTIONS

Fraction	Decimal	Fraction	Decimal
1/64	.015625	33/64	.515625
1/32	.03125	17/32	.53125
3/64	.046875	35/64	.546875
1/16	.0625	9/16	.5625
5/64	.078125	37/64	.578125
3/32	.09375	19/32	.59375
7/64	.109375	39/64	.609375
1/8	.125	5/8	.625
9/64	.140625	41/64	.640625
5/32	.15625	21/32	.65625
11/64	.171875	43/64	.671875
3/16	.1875	11/16	.6875
13/64	.203125	45/64	.703125
7/32	.21875	23/32	.71875
15/64	.234375	47/64	.734375
1/4	.25	3/4	.75
17/64	.265625	49/64	.765625
9/32	.28125	25/32	.78125
19/64	.296875	51/64	.796875
5/16	.3125	13/16	.8125
21/64	.328125	53/64	.828125
11/32	.34375	27/32	.84375
23/64	.359375	55/64	.859375
3/8	.375	7/8	.875
25/64	.390625	57/64	.890625
13/32	.40625	29/32	.90625
27/64	.421875	59/64	.921875
7/16	.4375	15/16	.9375
29/64	.453125	61/64	.953125
15/32	.46875	31/32	.96875
31/64	.484375	63/64	.984375
1/2	.5	1	1.

—*Courtesy American Machinist*

V. COMPARISON OF WIRE GAUGES

Gauge No.	Brown & Sharp or American			Birmingham or Stubs	W. & M. and Roebling	British Standard or Imperial	U. S. Standard	Gauge No.
	Diameter in Inches	Area Square Inches	Area Circular Mils	Diameter of Wire in Inches				
0000	46000	.166	212,000.0	454	.393	.400	406	0000
000	40964	.132	168,000 0	425	.362	372	375	000
00	36480	105	133,000 0	380	.331	348	.344	00
0	32486	0829	106,000.0	.340	307	324	313	0
1	28930	0657	83,700 0	300	.283	300	281	1
2	25763	0521	66,400 0	284	263	276	266	2
3	22942	0413	52,600.0	259	244	252	.250	3
4	20431	0328	41,700 0	238	.225	232	234	4
5	.18194	0260	33,100 0	220	207	212	.219	5
6	.16202	0206	26,300 0	.203	.192	.192	203	6
7	.14428	0164	20,800 0	180	177	176	188	7
8	.12849	0130	16,500 0	165	.162	160	172	8
9	11443	0103	13,100 0	148	.148	141	156	9
10	10189	00815	10,400 0	134	135	128	.141	10
11	09074	00647	8,230 0	120	120	116	125	11
12	08081	00513	6,530 0	.109	.105	104	.109	12
13	.07196	00407	5,180 0	095	.092	092	0938	13
14	06408	00323	4,110 0	083	080	080	.0781	14
15	05706	00256	3,260.0	072	.072	072	0703	15
16	.05082	00203	2,580 0	065	063	064	0625	16
17	.04525	00161	2,050 0	058	.054	056	0563	17
18	04030	.00128	1,620 0	049	.047	048	0500	18
19	.03589	.00101	1,290.0	.042	041	040	0438	19
20	03196	000802	1,020.0	035	035	.036	0375	20
21	.02846	000636	810 0	032	.032	032	0344	21
22	.02535	.000505	642 0	.028	.028	028	0313	22
23	.02257	.000400	509 0	.025	.025	024	0281	23
24	02010	.000317	404 0	.022	.023	022	.0250	24
25	.01790	000252	320 0	020	020	020	.0219	25
26	.01594	.000200	254.0	.018	.018	018	.0188	26
27	.01420	000158	202 0	016	.017	0164	0172	27
28	01264	.000126	160.0	.014	.016	0148	0156	28
29	.01126	0000995	127 0	.013	015	0136	0141	29
30	.01003	.0000789	101 0	.012	014	.0124	.0125	30
31	.00893	.0000626	79 7	.010	.013	.0116	.0109	31
32	.00795	.0000496	63 2	.009	.012	0108	.0102	32
33	.00708	.0000394	50 1	.008	011	.010	0094	33
34	.00630	.0000312	39 8	.007	.010	0092	.0086	34
35	.00561	0000248	31.5	.005	.0095	.0084	.0078	35
36	.00500	.0000196	25 0	004	.009	0076	.0070	36
37	00445	.0000156	19 8	....	.0085	.0068	0066	37
38	.00397	.0000123	15 7	...	.008	006	.0063	38
39	00353	.0000098	12.5	...	.0075	.0052	....	39
40	.00314	.0000078	9 9	...	.007	0048	....	40
41	.002800	.....	.....	....	....	.0044	....	41
42	.002494	......	......	....	....	.004	....	42
43	.002221	......	......	...	....	.0036	....	43
44	.001978	......	......	....	....	.0032	....	44
45	.001761	......	......	....	....	.0028	..	45
46	.001568	.....	......	...	...	.0024	...	46
47	.001397	......	......	....	....	.002	...	47
48	.001244	......	.....	....	....	.0016	....	48
49	.001018	......	......	....	....	0012	....	49
50	.0009863	......	......	...	....	.001	....	50

VI. SPECIFIC GRAVITY AND HEAT CONSTANTS

Substance	*Specific Gravity Water = 1*	*Melting Point °C*	*Boiling Point °C*	*Specific Heat*	*Linear Coefficient of Expansion (1°C)*
Alcohol, grain	0.789	–117.3	78.5	0.58	
Alcohol, wood	0.792	–97.8	64.5		
Aluminum	2.7	658.7	1800	0.22	0.000023
Brass	8.2–8.7	1067	2100	0.089	0.000018
Carbon tetrachloride	1.595	–23.0	76.8		
Copper	8.9	1083	2300	0.093	0.000017
Ether	0.714	–116.3	34.5	0.54	
Glass, crown	2.4–2.8			0.161	0.000009
Glycerine	1.26	17.9	290	0.58	
Gold	19.3	1063	2600	0.0316	0.000014
Kerosene	0.8		150–300	0.5–0.6	
Ice	.917	0		.502	
Iron, cast	7.0–7.2	1100		0.119	0.000010
Iron, wrought	7.6–7.9	1530		0.115	0.000011
Lead	11.3	327.4	1620	0.031	0.000029
Magnesium	1.74	651	1110	0.246	0.000021
Mercury	13.6	–38.9	357	0.032	
Platinum	21.45	1755		0.032	0.000009
Quartz	2.5–2.8			0.174	
Silver	10.5	961	1950	0.056	0.000019
Steel	about 7.7	1375		0.118	0.000011
Sulphur	2.0	112.8	444.6	0.180	0.000064
Sulphuric acid	1.834	10.49		0.336	
Tin	7.3	232	2260	0.055	0.000020
Zinc	7.1	419	907	0.093	0.000033

VII. CENTIGRADE - FAHRENHEIT CONVERSION CHART